REMOTE SENSING BASED EVALUATION OF UNCERTAINTIES ON MODELLING OF STREAMFLOW AFFECTED BY CLIMATE CHANGE

TAN MOU LEONG

UNIVERSITI TEKNOLOGI MALAYSIA

REMOTE SENSING BASED EVALUATION OF UNCERTAINTIES ON MODELLING OF STREAMFLOW AFFECTED BY CLIMATE CHANGE

TAN MOU LEONG

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Remote Sensing)

Faculty of Geoinformation and Real Estate
Universiti Teknologi Malaysia

FEBRUARY 2016

DEDICATION

To my beloved mother and father

ACKNOWLEDGEMENT

First and foremost, I would like to express my warm and sincere gratitude to my main supervisor, Assoc. Prof. Dr. Ab Latif Ibrahim who encouraged me to further my study at Ph.D level. I very appreciated the liberty he gave me to develop my own ideas and motivated me all the time. A special thanks to my co-supervisor, Prof. Dr. Zulkifli Yusop who was always willing to share his immense knowledge on my research. My sincere thanks also goes to Prof. Dr. Arthur P Cracknell, for proof-reading the thesis and thereby significantly improving the English of the thesis. The funding for this PhD was provided by the Ministry of Higher Education (MOHE) Malaysia under the Fundamental Research Grant Scheme (VOT no: R.J120000.7827.4F213) and MyBrain 15 program. I am deeply grateful to my parents, Tan Kok Hing and Chan Yoke Tan, who along with my brother and sisters gave me continuous support. I finally would like to thank my girlfriend, Tan Lee Siang, who always stood by my side and shared the difficult moments.

ABSTRACT

Assessment of the impacts of land-use and climate change on streamflow is vital to develop climate adaptation strategies. However, uncertainties in the climate impact study framework could lead to changes on streamflow impact. The aim of this study is to assess the uncertainties on Digital Elevation Model (DEM), Satellite Precipitation Product (SPP) and climate projection on the modelling of streamflow affected by climate changes. These uncertainties are evaluated and reduced independently. The climate projection uncertainty is addressed through the modification of the Quantifying and Understanding the Earth System - Global Scale Impacts (QUEST-GSI) methodology. Twenty-six modified QUEST-GSI climate scenarios were used as climate inputs into the calibrated Soil and Water Assessment Tool (SWAT) model to evaluate the impacts and uncertainties of climate change on streamflow for three future periods (2015-2034, 2045-2064 and 2075-2094). The selected study areas are the Johor River Basin (JRB) and Kelantan River Basin (KRB), Malaysia. The Shuttle Radar Topography Mission (SRTM) version 4.1 (90m resolution) DEM and the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks – Climate Data Record (PERSIANN-CDR) SPP which show a better performance were selected for the SWAT model modification, calibration and validation. The results indicated that the modified SWAT model could simulate the monthly streamflow well for both basins. Land-use and climate changes from 1985 to 2012 reduced annual streamflow of the JRB and KRB by 5% and 4.2%, respectively. In future, the annual precipitation and temperature of the JRB / KRB are projected to increase by -0.4-10.3% / 0.1-11.2% and 0.6-3.2ºC / 0.8-3.3ºC, respectively, and that this will lead to an increase of annual streamflow by 0.5-13.3% / 4.4-18.5%. This study showed that satellite data play an important role in providing input data to hydrological models.

ABSTRAK

Penilaian kesan guna-tanah dan perubahan iklim terhadap aliran sungai adalah penting bagi membangunkan strategi penyesuaian iklim. Namun, ketidakpastian dalam rangka kerja kajian kesan iklim akan menyebabkan perubahan kepada kesan aliran sungai. Tujuan kajian ini adalah untuk menilai ketidakpastian dalam model ketinggian berdigit (DEM), produk hujan satelit (SPP) dan unjuran iklim kepada pemodelan aliran sungai terjejas oleh perubahan iklim. Ketidakapastian ini dinilai dan dikurangkan secara berasingan. Ketidakpastian unjuran iklim ditentukan melalui pengubahsuaian metodologi hitungan dan pemahaman sistem bumi – impak skala global (QUEST-GSI). Duapuluh enam senario iklim QUEST-GSI yang telah diubahsuai digunakan sebagai input kepada model penilaian tanah dan air (SWAT) yang telah dikalibrasi untuk menilai kesan dan ketidakpastian perubahan iklim terhadap aliran sungai untuk tiga jangka masa yang akan datang (2015-2034, 2045-2064 dan 2075-2094). Tempat kajian adalah Lembangan Sungai Johor (JRB) dan Lembangan Sungai Kelantan (KRB), Malaysia. Misi topografi radar pengangkutan ulang-alik (SRTM) versi 4.1 (90m resolusi) DEM dan anggaran hujan dari informasi penderiaan jauh menggunakan jaringan neural buatan – rekod data iklim (PERSIANN-CDR) SPP yang menunjukkan prestasi lebih cermerlang telah dipilih bagi pengubahsuaian, kalibrasi dan pengesahan model SWAT. Keputusan menunjukkan model SWAT yang diubahsuai dapat mesimulasikan aliran sungai bulanan dengan baik bagi kedua-dua lembangan. Perubahan guna-tanah dan iklim dari 1985 hingga 2012 telah mengurangkan aliran sungai tahunan bagi JRB dan KRB masing-masing sebanyak 5% dan 4.2%. Hujan dan suhu tahunan masa depan bagi JRB / KRB dijangka meningkat masing-masing sebanyak -0.4-10.3% / 0.1-11.2% dan 0.6-3.2^{o}C / 0.8-3.3^{o}C, dan akan menyebabkan peningkatan aliran sungai tahunan sebanyak 0.5-13.3% / 4.4-18.5%. Kajian ini menunjukkan data satelit memainkan peranan penting dalam menyediakan data input kepada model hidrologi.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

$\overline{P}_x$	-	Mean of the DEM elevation
$\overline{P}_{ref}$	-	Mean of reference elevation
$\vartriangle P(x,y)$	-	Precipitation different between the satellite and observed data at a given point
$P_{S(x,y)}$	-	Satellite precipitation at a specific location (x,y)
$P_{G(x,y)}$	-	Gauge precipitation at a specific location (x,y)
$\vartriangle P_{(x,y)\mathrm{int}}$	-	Spatially interpolated different map
$P_{s.corrected}$	-	Satellite precipitation after correction
SW_t	-	Final soil water content
SW_o	-	Initial soil water content on day *i*
R_{day}	-	The amount of precipitation on day *i*
Q_{surf}	-	Amount of surface runoff on day *i*
E_a	-	Amount of evapotranspiration on day *i*
w_{seep}	-	Amount of water entering the vadose zone from the soil profile on day *i*
Q_{gw}	-	Amount of return flow on day *i*
Q_{surf}	-	Accumulated runoff or rainfall excess
R_{day}	-	Rainfall depth for the day
I_a	-	Initial abstraction which includes surface storage, interception and infiltration prior to runoff
S	-	Retention parameter

$f_{inf,t}$	-	Infiltration rate at time *t*
K_e	-	Effective hydraulic conductivity
ψ_{wf}	-	Wetting front matric potential
$\Delta\theta_v$	-	Change in volumetric moisture content across the wetting front
$F_{inf,t}$	-	Cumulative infiltration at time *t*
E_o	-	Potential evapotranspiration
λ	-	Latent heat of vaporization
H_o	-	Extra-terrestrial radiation
T_{mx}	-	Maximum air temperature for a given day
T_{mn}	-	Minimum air temperature for a given day
$\bar{T}_{av}$	-	Mean air temperature for a given day
q_{ch}	-	Rate of flow in the channel
A_{ch}	-	The cross-sectional area of flow in the channel
R_{ch}	-	Hydraulic radius for a given depth of flow
slp_{ch}	-	Slope along the channel length
n	-	Manning's coefficient for the channel
ΔV_{stored}	-	Change in volume of storage during the time step
V_{in}	-	Volume of inflow during the time step
V_{out}	-	Volume of outflow during the time steps
q_{in}	-	Inflow rate
q_{out}	-	Discharge rate
K	-	Storage time constant for the reach
X	-	Weighting factor
$\bar{o}$	-	Mean observed streamflow
$\bar{p}$	-	Mean simulated streamflow
$T_{delta,daily}$	-	Delta downscaled daily temperature
$T_{obs,daily}$	-	Observed daily temperature
$\bar{T}_{fut}$	-	GCM average monthly temperature of the future period

$\bar{T}_{bas}$	-	GCM average monthly temperature of the baseline period
$P_{delta,daily}$	-	Delta downscaled daily precipitation
$P_{obs,daily}$	-	Observed daily precipitation
$\bar{P}_{fut}$	-	GCM average monthly precipitation of the future period
$\bar{P}_{bas}$	-	GCM average monthly precipitation of the baseline period
'	-	Minute
"	-	Second
%	-	Percentage
±	-	Plus-minus
°	-	Degree
A	-	Hits (event forecast to occur, and did occur)
ACC	-	Accuracy
B	-	False alarm (event forecast to occur, but did not occur)
C	-	Misses (event forecast not to occur, but did occur)
CH_K2	-	Channel effective hydraulic conductivity
CH_N2	-	Manning’s value for main channel
CN2	-	Initial SCS Curve Number II value
CSI	-	Critical success index
D	-	Correct negative (event forecast not to occur but occur)
Ensemble_5	-	Ensemble of five selected GCMs
ESCO	-	Soil evaporation compensation factor
FAR	-	False alarm ratio
G	-	Gauge precipitation
GHz	-	Gigahertz
GW_REVAP	-	Groundwater “revap” coefficient
GWQMN	-	Threshold water depth in the shallow aquifer for flow
HSS	-	Heidke skill score
km	-	Kilometre
km^2	-	Square kilometre
km^3	-	Cubic kilometre
km^3/year	-	Cubic kilometre per year
m	-	Metre

m.a.s.l	-	Above mean sea level
m^3/day	-	Cubic metre per day
m^3s^{-1}	-	Meter cubic per second
ME	-	Mean error
$MJkg^{-1}$	-	Megajoules per kilogramme
mm/day	-	Millimetre per day
mm/day	-	Millimeter per day
mm/month	-	Milimetre per month
mm/year	-	Millimetre per year
n	-	Number of gcps
NME	-	Normalize mean error
NRMSE	-	Normalize root mean square error
NSE	-	Nash sucliffe efficiency
o	-	Observed streamflow
^{o}C	-	Celsius
^{o}N	-	North
^{o}S	-	South
p	-	Simulated streamflow
PB	-	Percentage bias
POD	-	Probability of detection
P_{ref}	-	Reference elevation (gcps from topographic map)
P_{x}	-	DEM elevation
R^2	-	Coefficient of determination
RB	-	Relative bias
REVAP_MN	-	Threshold depth of water in the shallow aquifer for “revap” to occur
RMSE	-	Root mean square error
RSR	-	Ratio of root mean square error
S	-	Satellite precipitation
SB	-	Sub-basin
SOL_AWC	-	Available water capacity
t	-	Time
Tmax	-	Maximum temperature

Tmean	-	Mean temperature
Tmin	-	Minimum temperature
UTC	-	Coordinated universal time
Wm^{-2}	-	Watt per square metre

LIST OF ABBREVIATIONS

3D	-	Three dimensional
ACCESS1-0	-	Australia Community Climate and Earth System Simulator, version 1
AMJ	-	April, May and Jun
ANION_EXCL	-	Fraction of porosity (void space) from which anions are excluded
AOGCMs	-	Atmospheric-ocean general circulation models
APHRODITE	-	Asian Precipitation Highly Resolved Observational Data Integration Towards the Evaluation of Water Resources
AR4	-	Assessment Report 4
AR5	-	Assessment Report 5
ASTER	-	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	-	Advanced Very High Resolution Radiometer
BCC-CSM1-1	-	Beijing Climate Centre Climate System Model, version 1.1
BNU-ESM	-	Beijing Normal University, Earth System Model
CanESM2	-	Canadian Earth System Model, version 2
Cat-PDM	-	Probability Distributed Model
CCCma	-	Canadian Centre for Climate Modelling and Analysis
CCSM3	-	Community Climate System Model, version 3
CCSM4	-	Community Climate System Model, version 4
CESM1-CAM5	-	Community Earth System Model- Community Atmosphere Model
CGCM3.1	-	Canadian Coupled General Climate Model, version 3.1

CGIAR-CSI	-	Consortium for Spatial Information of the Consultative Group of International Agriculture Research
CLAY1	-	Clay content of the first layer of soil
CMIP 3	-	Coupled Model Intercomparison Project Phase 3
CMIP 5	-	Coupled Model Intercomparison Project Phase 5
CMORPH	-	Climate Prediction Center Morphing Technique
CN	-	Curve Number
CNES	-	Centre national d'études spatiales – the French space agency
CNRM-CM5	-	Centre National de Recherches Meteorologiques- Coupled Global Climate Model, version 5
CRU-TS	-	Climatic Research Unit- Time series
CSIRO-Mk3-6-0	-	Commonwealth Scientific and Industrial Research Organization- Mark Climate Model, version 3.6
CSIRO-Mk3.0	-	Commonwealth Scientific and Industrial Research Organization- Mark Climate Model, version 3.0.
DEMs	-	Digital Elevation Models
DEWPT	-	Average daily few point temperature per month of the year in degree celcius
DID	-	Department Irrigation And Drainage
EC-EARTH	-	European Centre Earth System Model
EGM96	-	Earth Gravitational Model 1996
EM	-	East Malaysia
EM-DAT	-	International Emergency Disasters Database
ENO	-	Environment and Organism
ET	-	Evapotranspiration
ETM+	-	Enhanced Thematic Mapper Plus
FELDA	-	Federal Land Development Authority
FGOALS-g2	-	Flexible Global Ocean-Atmosphere-Land System model, Grid-point version 2
FRIM	-	Forest Research Institute Malaysia
GCMs	-	General Circulation Models
GCPs	-	Ground control points
GDA	-	Geographic Differential Analysis

GDEM	-	Global Digital Elevation Model
GFDL-CM3	-	Geophysical Fluid Dynamics Laboratory Coupled Model, version 3
GFDL-ESM 2M	-	Geophysical Fluid Dynamics Laboratory- Earth System Model, version 2
GHCN2	-	modified version of Global Historical Climatology Network
GHG	-	Greenhouse Gas
GLSDEM	-	Global Land Survey Digital Elevation Model
GOES	-	Geostationary Operational Environmental Satellite system
GPCC	-	Global Precipitation Climatology Center
GPCP	-	Global Precipitation Climatology Project
GPCP-1DD	-	GPCP – one degree daily
GRA	-	Geographical Ratio Analysis
HadCM3	-	Hadley Centre Coupled Model, version 3
HadGEM1	-	Hadley Centre Global Environment Model, version 1
HadGEM2-ES	-	Hadley Centre Global Environment Model version 2 Earth System
HBV	-	Hydrological Simulation Model
HeC-HMS	-	Hydrologic Engineering Center-Hydrologic Modeling System
HESS	-	Hydrology and Earth System Sciences
HRUs	-	Hydrologic Response Units
HSPF	-	Hydrologic Simulation Package-Fortran
HYDGRP	-	Soil hydrologic group
IDW	-	inverse distance weighting
INM-CM4	-	Institute for Numerical Mathematics Climate Model, version 4
IPCC	-	Intergovernmental on Climate Change
IPSL-CM4	-	Institut Pierre Simon Laplace- Climate Model, version 4.
IPSL-CM5A-MR	-	Institut Pierre Simon Laplace- Coupled Model 5A- Medium Resolution.
IR	-	Thermal infrared
IRS 1D LISS-3	-	Indian Remote Sensing 1D Linear Imaging Self-Scanning System III

JAS	-	July, August and September
JFM	-	January, February and March
JPEG	-	Joint Photographic Experts Group
JRB	-	Johor River Basin
JUPEM	-	Jabatan Ukur dan Pemetaan Malaysia
KEJORA	-	South East Johore Development Authority
KINEROS	-	Kinematic Runoff and Erosion
KRB	-	Kelantan River Basin
LAI	-	Leaf Area Index
LAMs	-	Limited Area Models
LH-OAT	-	Latin hypercube sampling by one at a time design
LULC	-	Land use land cover
MAE	-	Mean absolute error
MARDI	-	Malaysian Agriculture Research and Development Institute
ME	-	Mean error
METI	-	Ministry of Economy, Trade, and Industry of Japan
MIKE-SHE	-	Mike- Système Hydrologique Européen
MIROC5	-	Model for Interdisciplinary Research on Climate, version 5
MIROC-ESM	-	Model for Interdisciplinary Research on Climate- Earth System Models
MMD	-	Malaysia Meteorological Department
MOA	-	Ministry of Agriculture and Agro-based Industry Malaysia
MODIS	-	Moderate Resolution Imaging Spectroradiometer
MPI	-	Max Planck Institute for Meteorology
MRI-CGCM3	-	Meteorological Research Institute- Coupled General Circulation Model, version 3
MSL	-	Mean sea level
MW	-	Microwave
NAHRIM	-	National Hydraulic Research Institute Malaysia
NASA	-	National Aeronautics and Space Administration
NCAR	-	National Center for Atmospheric Research
NCEAS	-	National Center for Ecological Analysis and Synthesis

NCEP/NCAR	-	National Centers for Environment Prediction/National Center for Atmospheric Research
NDVI	-	Normalized Difference Vegetation Index
NEM	-	Northeast monsoon
NIMA	-	National Imagery and Mapping Agency
NLAYERS	-	Number of layers in the soil
NorESM1-M	-	Norwegian Climate Center’s Earth System Model
OND	-	October, November and December
PCMDI	-	Program for Climate Model Diagnosis and Intercomparison
PCPD	-	Average numbers of days of precipitation for each month
PCPMM	-	Average total of monthly precipitation in millimeters
PCPSKW	-	Skew coefficient for daily precipitation for each month
PCPSTD	-	Standard deviation for daily precipitation in each month, expressed as in mm of water per day
PDF	-	Probability distribution function
PERSIANN	-	Precipitation Estimation from Remotely Sensed Information Using Artificial Neural Network
PERSIANN-CDR	-	Precipitation Estimation from Remotely Sensed Information Using Artificial Neural Network – Climate Data Record
PM	-	Peninsular Malaysia
PMW	-	Passive microwave
PR	-	Precipitation radar
PR_W1	-	Probability of a wet day following a dry day for each month
PR_W2	-	Probability of a wet day following a wet day for each month
PRMS	-	Precipitation Runoff Modelling System
PUB	-	Public Utility Board
QUEST-GSI	-	Quantifying and Understanding the Earth System – Global Scale Impacts
RAIN_YRS	-	Number of years of maximum monthly half hour rainfall data used to define values for averages per month of the year.
RAINHHMX	-	Most extreme half-hour precipitation for each month
RB	-	Relative bias
RCMs	-	Regional Climate Models

RCP	-	Representative Concentration Pathway
RegHCM-PM	-	Regional Hydroclimate Model of Peninsular Malaysia
RegHCM-SS	-	Regional Hydroclimate Model of Sabah and Sarawak
ROCK1	-	Rock fragment content of the first layer of soil
SAJ	-	Johor Water Company
SAND1	-	Sand content of the first layer of soil
SCS	-	Soil Conservation Services
SDSM	-	Statistical Downscaling Model
SILT1	-	Silt content of the first layer of soil
SLURP	-	Semi-distributed Land Use-based Runoff Processes
SNSB	-	Swedish Natioanal Space Board
SOL_ALB1	-	Moist soil albedo of the first layer of soil
SOL_AWC1	-	Available water capacity of the first layer of soil
SOL_BD1	-	Moist bulk density of the first layer of soil
SOL_CAL1	-	Calcium carbonate content of the first layer of soil
SOL_CBN1	-	Organic carbon content of the first layer of soil
SOL_CRK	-	Crack volume potential of soil
SOL_EC1	-	Soil electrical conductivity of the first layer of soil
SOL_K1	-	Saturated hydraulic conductivity of the first layer of soil
SOL_PH1	-	Soil PH of the first layer of soil
SOL_Z1	-	Depth from soil surface to bottom of the first layer of soil
SOL_ZMX	-	Maximum rooting depth of soil profile
SOLARAV	-	Average daily solar radiation for each month
SPOT	-	Satellite Pour l'Observation de la Terre
SPPs	-	Satellite Precipitation Products
SRES	-	Special Report on Emissions Scenarios
SRTM	-	National Aeronautics And Space Administration Shuttle Radar Topography Mission
SSTC	-	Technical and cultural services
SUFI-2	-	Sequential Uncertainty Fitting
SWAT	-	Soil and Water Assessment Tool
SWAT-CUP	-	SWAT Calibration And Uncertainty Procedures
SWM	-	Southwest monsoon

TCI	-	TRMM Combined Instrument
TEXTURE	-	Texture of soil layer
TMI	-	TRMM Microwave Imager
TMPA	-	TRMM Multi-satellite Precipitation Analysis
TMPI	-	Threshold-matched precipitation index
TMPMN	-	Average daily maximum air temperature for each month in degrees celsius
TMPMX	-	Average daily maximum air temperature for each month in degrees celsius
TMPSTDMN	-	Standard deviation for daily minimum air temperature for each month in degrees celcius
TMPSTDMX	-	Standard deviation for daily maximum air temperature for each month in degrees Celsius
TOPMODEL	-	Topography Based Hydrological Model
TRMM	-	Tropical Rainfall Measuring Mission
UBC	-	University Of British Columbia Model
UKMO	-	United Kingdom Meteorological Office
UNEP	-	United Nations Environment Program
UNISDR	-	United Nations International Strategy for Disaster Reduction
USA	-	Unite States of America
USD	-	United States Dollar
USDA	-	United States Department of Agriculture
USGS	-	United States Geological Survey
USLE_K1	-	USLE equation soil erodibility (K) factor of the first layer of soil
VIC	-	Variable Infiltration Capacity
VIS	-	Visible
WCRP	-	World Climate Research Programme
WELEV	-	Elevation of the weather station in meters above mean sea level
WGN	-	Weather generator
WLATITUDE	-	Latitude of the weather station
WLONGTITUDE	-	Longitude of the weather station

WMO	-	World Meteorological Organization
WNDAV	-	Average daily wind speed for each month

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Water is crucial for human survival. The distribution of fresh water in our planet is about 2.5% of the total amount of water, of this 68.6% is deposited in glaciers and ice caps, 30.1% in ground water and only 1.3% is found in surface water bodies such as swamps, rivers and lakes (Gleick, 1993). Surface water exists in very small amounts and is exposed to many threats caused by human activities including deforestation, pollution and climate change (e.g. Tu *et al.*, 2015; Wang *et al.*, 2015). Water resources are affected by global change, for example water demand increases due to population growth and water availability imbalance owing to climate and land use changes.

Streamflow is the flow of water in channels, rivers or streams and is one of the major components of the hydrological cycle. In general, streamflow is composed of a "slow" component called baseflow (Hall, 1968) and a "fast" component referred as surface runoff (Jakeman and Hornberger, 1993). Both components are mainly controlled by basin attributes such as soil, geology, climate, topography and land cover type (Kirkby *et al.*, 2002; Price, 2011). Streamflow serves an important role in drinking water, hydropower, transportation, agriculture and the industrial sector.

Nevertheless, streamflow also brings some negative implications for society and environment such as flood and drought events (Hannaford, 2015). Based on the EM-DAT International Disaster Database, flood events from 1900 to 2014 have caused about 7 million deaths, with 3.6 billion people affected and 670 billion USD damage (http://www.emdat.be/database, accessed on 17 December 2014). Most of the severe cases occurred in tropical developing countries (UNISDR, 2011). During the December 2014 to January 2015, the monsoon flood in Malaysia affected more than 230,000 people, caused 23 deaths and cost 560 million USD damage.

Streamflow information is necessary for most of the water resources management projects (Seyam and Othman, 2015). Time series of streamflow record is crucial for flood forecasting, climate change assessment, water quality evaluation and aquatic habitat simulation (Smith and Pavelsky, 2008; Bourdin *et al.,* 2012; Ravazzani *et al.*, 2015). Better streamflow prediction and forecasting gives multiple benefits such as better water use management through anticipation of river inflow, improved capability in flood forecasting and monitoring as well as a better understanding of river water dynamics for hydropower planning (Barrett *et al.*, 2008). However, the availability and scarcity of in-situ streamflow measurements remain a critical issue in many developing countries. In many river basins, lack of data often hampers the judicious management of water resources (Hirpa *et al.*, 2013).

Remote sensing is known as a technology to retrieve information about an object without any physical contact to that object (Congalton, 2010). The ability of remote sensing in streamflow measurement has been identified and proven, either by providing input parameters to streamflow modelling or indirectly estimating the streamflow through satellite imagery (Rango, 1994; Bjerklie *et al.,* 2003; Brakenridge *et al.,* 2005; Sun *et al.,* 2015). The potential of remote sensing for providing information to hydrologists has been well recognized since the ability of Landsat-1 imagery to provide land use information for hydrological modelling (Rango, 1994; Pietroniro and Leconte, 2005).

Generally, the application of remote sensing in hydrology can be divided into three main classes including: (1) the delineation of known water features such as lakes and rivers; (2) estimating information like geological features or land use through classification and interpretation of satellite imagery; (3) the retrieval of hydrological parameters such as precipitation, evaporation, soil moisture and a digital elevation model directly from satellite imagery (Pietroniro and Leconte, 2000; Pietroniro and Prowse, 2002). Compared to the in-situ measurements by point-based gauge stations, the benefits of remote sensing to hydrology include the provision of spatial data of the area of interest, long term and global information for remote or inaccessible areas (Engman, 1996; Ritchie and Rango, 1996; Silvestro *et al.,* 2015). However, the uncertainties of satellite data in hydrological modelling and calibration of a hydrological model using satellite data are challenging topics, which are main focuses of this study.

Precipitation is an important input of water in the hydrological cycle and is the main source of catchment water (Kidd and Levizzani, 2011). Accurate and reliable precipitation information is therefore necessary to ensure better water resource management and decision-making in the various areas using water, such as agriculture, industries, and cities. Satellite precipitation products (SPPs) are widely accepted as an alternative source to overcome the limitations of ground techniques (Pan *et al.,* 2014). Recently, satellite information has become available at high spatial (up to 0.25 °) and temporal (near real time) resolutions and over large areas (near global). However, estimations using SPPs are subjected to bias and stochastic errors, which depend highly on the hydro-climatic characteristics of a region (Barrett 1993; Yilmaz *et al.*, 2005). Therefore, performance evaluation of SPPs in different regions is essential to enable users and algorithm developers to better understand and quantify such errors.

Digital Elevation Models (DEMs) are one of the most important spatial input datasets in hydrological modelling (Wu *et al.,* 2008; Bourdin *et al.,* 2012). DEMs constitute a key spatial layer for estimating a watershed's channel networks, slope gradients, flow direction and accumulations, and several other controls of the water movements in landscapes (Moore *et al.,* 1991; Wechsler, 2007). While the lack of DEM availability was an important issue a decade ago, this problem has largely been solved due to the widespread availability of global remotely sensed DEM products (Lin *et al.,* 2013) such as from the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) and the Shuttle Radar Topography Mission (SRTM). However, the selection of appropriate products for hydrological applications remains an important issue.

Land use change is likely to impact the water resources availability and hydrological cycle by modification in infiltration rate, interception and evapotranspiration (Chawla and Mujumdar, 2015). A multitude of natural factors such as seasonal variations in land cover characteristics and natural maturation of forest can lead to changes in land use (Öztürk *et al.,* 2013). Besides that, anthropogenic factors include deforestation, urbanization, agriculture activities, and forest management practices would also change the land use pattern. Recently, many researchers have evaluated the relationship between hydrological cycle components and land use changes (Li *et al.*, 2015; Mateus *et al.*, 2015; Nazir *et al.*, 2015; Soulis *et al.*, 2015).

Climate change is generally known as the changes in the earth's climatic condition and persists for a long term period (IPCC, 2012). The climate system is very sensitive and closely interconnected with the hydrological cycle (Zhao *et al.*, 2015). Any perturbation of the climate system will temporarily or permanently alter the hydrological cycle and lead to a significant impact on water resources (Bates *et al.*, 2008). The current water management systems are expected to be unable to cope with future climate changes; therefore, integration of climate impact information in the adaptation strategy is now a priority for each country (Wilby *et al.,* 2009).

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC-AR5) chapter three - the most up-to-date scientific assessment of past, present and potential future climate on freshwater resources - reported that water-related hazards such as river floods and droughts are expected to increase significantly with increasing precipitation and temperature (Jiménez Cisneros *et al*., 2014). Hence, the potential of land use and climate change impacts on the hydrological cycle have received attention from numerous researchers in different regions of the world (Maurer *et al.*, 2009; Tsai and Huang, 2011; Wang *et al.*, 2012; Dessu and Melesse, 2013; Ficklin *et al.*, 2013a; Khoi and Suetsugi, 2014a; Gao *et al.*, 2015).

Generally, most of the hydro-climatic impact assessment studies adopt a "top down" framework by applying downscaled projected climate data of General Circulation Models (GCMs) into a calibrated hydrological model (Maurer *et al.*, 2009; Taye *et al.*, 2011) (Figure 1.1). Each component of the "top down" framework (Figure 1.1) contains a degree of uncertainty which leads to changes in the measured impact response (Wilby *et al.*, 2009). Hence, each component's uncertainties need to be quantified in order to provide robust impact information (Wilby *et al.*, 2008).

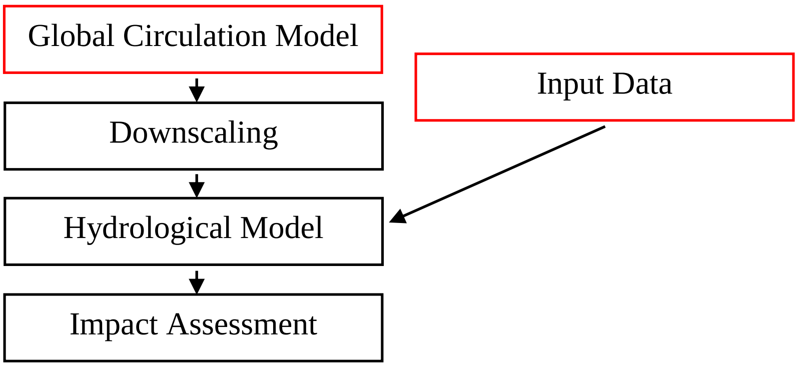

Figure 1.1 "Top down" framework for climate change impact on hydrological cycle studies (red colour boxes are components that are addressed in this study)

The selected hydrological model, the Soil and Water Assessment Tool (SWAT) is one of the most popular models. It was developed by the United States Department of Agriculture (USDA) to evaluate the impact of agriculture management on water at a basin scale (Arnold *et al.,* 1998). SWAT has proved to be a reliable tool for studying climate change impact on streamflow around the world (Zeng *et al.,* 2012; Kankam-Yeboah *et al.,* 2013; Le *et al.,* 2015; Mehdi *et al.,* 2015; Serpa *et al.,* 2015; Uniyal *et al.,* 2015). There are relatively few studies which have applied SWAT to simulate streamflow in Malaysia.

1.2 Statement of the Problem

With the development of remote sensing and computer systems, the traditional basin delineation approaches are now rapidly being replaced by automatic approaches. For example, DEM-based basin delineation gives advantages such as cost saving, efficient and faster processing. However, such an approach might lead to sub-basins and river networks mismatch issues, especially in a plain polder area (Luo *et al.,* 2011). Therefore, an improved DEM-based basin delineation and river network correction approach is required to impove modelling of streamflow with the realistic hydrological process.

The capability of a hydrological model to accurately simulate streamflow is highly dependent on the quality of the input data (Bourdin *et al.,* 2012). Satellite precipitation data potentially constitutes an alternative to sparse rain gauge networks for assessing the spatial distribution of precipitation (Casse *et al.,* 2015). However, the uncertainties in the satellite precipitation might propagate in hydrological models and need to be accounted for before applying it to hydrological models (Nikolopoulos *et al.,* 2010; Bajracharya *et al.,* 2015; Skinner *et al.,* 2015). Hence, evaluation of SPPs performance in rainfall estimation before hydrological modelling is very important to reduce uncertainties in final output.

Studies about the evaluation of SPPs in Malaysia appear to be limited. Varikoden *et al.* (2010) evaluated the daily precipitation from TRMM 3B42V6 data in Peninsular Malaysia, which covers only about 40% of the total area of Malaysia, using for validation only four precipitation gauges. Semire *et al*. (2012) validated the TRMM Microwave Imager (TMI) 2A12, 3B42V6, 3B43V6, and Global Precipitation Climatology Center (GPCC) with the monthly precipitation data collected over 10 years (2001–2010) from 22 precipitation gauges distributed over Malaysia. Both studies showed that 3B43V6 performs well over Malaysia, with a ±15% error bias at monthly scale. However, these studies have compared only one or two SPPs, thus limiting their conclusions. There are several other available SPPs that need to be tested such as the Global Precipitation Climatology Project (GPCP), Precipitation Estimation from Remotely Sensed Information Using Artificial Neural Network (PERSIANN), and Climate Prediction Center Morphing Technique (CMORPH). Moreover, the accuracy assessment of these products is also required at daily time steps.

The climate projection uncertainty assessment is a quantification of the feasible threshold of future hydro-climatic conditions (Dessu and Melesse, 2013). The Quantifying and Understanding the Earth System – Global Scale Impacts (QUEST-GSI) methodology developed by Todd *et al.* (2011) is an advanced method involving the unification of climate impacts and uncertainties scenarios for better comparison between different study areas and applying prescribed warming scenarios to advice mitigation policy. However, the QUEST-GSI methodology applied previous GCMs from the phase 3 Couples Model Intercomparison Project (CMIP3) and emission scenarios from the Special Report on Emission Scenarios (SRES). Hence, modification of the QUEST-GSI methodology is essential to fit with the latest climate research development.

The regional scale hydro-climatic assessment studies especially on the water sector in Malaysia are still limited, and there is no related research listed in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) (IPCC 2007; Tangang *et al*., 2012). Hydro-climatic impacts research in Malaysia has been receiving much more attention since 2007, due to the increase in climate impact awareness. Shaaban *et al.* (2012) have evaluated impacts of climate change on several major basins of Peninsular Malaysia for the 2025 to 2034 and 2041 to 2050 periods by using the Canadian Centre for Climate Modelling and Analysis (CCCma) under the IS92a emission scenario. However, the application of the latest emission scenarios (Moss *et al.,* 2010) and multiple GCMs assessment (Palmer *et al.,* 2008) is very important to reflect more robust impact analysis. In this study, the latest CMIP5 GCMs and emission scenarios released by the IPCC in 2014 were used, and the missing "end of the century" assessment was included.

Most of the studies were concerned with the changes of a single factor, i.e. either climate changes (Shaaban *et al*. 2011) or land-use changes (Amini *et al*. 2011). Adnan and Atkinson (2011) considered both impacts of land-use and climate changes in Malaysia by using a statistical analysis approach. The study was conducted in northeast Peninsular Malaysia and they found an increasing trend of streamflow and precipitation during the wet season. However, no hydrological modelling impact studies that consider both factors (land-use and climate) have been performed in other part of Peninsular Malaysia. This study aims to fill this research gap.

There are only a few studies that applied SWAT to simulate hydrological processes in Malaysia. Memarian *et al.* (2014) applied SWAT in the Hulu Langat River Basin to assess impact of land-use change and reported the Nash-Sutcliffe Efficiency (NSE) value of 0.73 in validation period. In the Upper Bernam River Basin, Alansi *et al.* (2009) reported the validated SWAT's NSE values range from 0.68 to 0.78. These studies found that SWAT showed moderate to good performance in northern and western Peninsular Malaysia. However, the capability of the SWAT model to simulate streamflow in east-coast and southern Peninsular Malaysia is still unclear. Parameters in the empirical equations within SWAT were derived from climate condition in the USA (Neitsch *et al.*, 2011) and these should be modified for application to tropical conditions, in order to obtain better hydrological simulation.

1.3 Research Questions

1. Which digital elevation model is suitable for SWAT modelling?
2. Which satellite precipitation product is suitable for providing rainfall information for hydro-climatic assessment?
3. What is the performance of the SWAT model in Malaysia?
4. To what extent were land use and climate changes influencing the streamflow?
5. How much change will there be in future streamflow under climate change impacts?

1.4 Objectives of the Study

The aim of this study is to explore and quantify the variability of climate change on streamflow variability. The specific objectives are outlined as follows:

1. To quantify the uncertainties of digital elevation models.
2. To evaluate and reduce the uncertainties of satellite precipitation products.
3. To modify the Soil and Water Assessment Tool (SWAT) for streamflow simulation in Malaysia.
4. To investigate the impacts of historical land-use and climate change on streamflow.
5. To assess the impacts and uncertainties of future climate change on streamflow.

1.5 Scope of the Study

The scope of this study can be divided into two parts. The first part involves the development of a SWAT model for the JRB. The input data sets are DEM, SPP, observed climate data (1985 to 2012), observed streamflow data (1985 to 2012), land use map and soil map. The SPP, land use map and DEM were generated from satellite data, while the observed climate, streamflow and soil map were collected from the relevant government agencies. The Latin hypercube sampling by one at a time design (LH-OAT) developed by Van Griensven *et al.* (2006) was used to perform sensitivity analysis and calibration procedure. It is an automatic sensitivity analysis embedded in the SWAT-CUP tool.

The second part was focused on the climate projection uncertainty analysis by using the modified QUEST-GSI methodology. The methodology was modified by incorporating the latest GCMs from the Phase 5 Coupled Model Intercomparison Project (CMIP5) and the Representative Concentration Pathways (RCPs) 2.6, 4.5 and 8.5 which represent low, medium and high emission scenarios, respectively.

Five GCMs with a good capability of historical precipitation simulation were selected from 18 GCMs for an average ensemble process and these GCMs were used for the hydro-climatic assessment. The ensemble of GCMs was used to replace a single GCM in the QUEST-GSI methodology. The periods set for impact assessment are 1985-2004(baseline), 2015-2034 (beginning of the century), 2045-2064 (mid of the century) and 2075-2094 (end of the century). The developed climate scenarios were used as inputs into the calibrated SWAT to assess impacts and uncertainties of climate change on future streamflow.

1.6 Significance of the Study

In hydrology, the DEM plays a vital role in providing the basin's topography information including channel network, slope and flow direction. Due to rigorous spatial data policies in most countries, many researchers prefer to choose public domain DEM products. Nowadays, there are many satellite sensors capable of producing DEMs and this will lead to difficulties for hydrologists to choose an appropriate DEM for their work. This study can be used by hydrologists to choose the best DEM for their study prior to the development of the hydrological modelling. Besides that, an improved DEM-based basin delineation and river network correction approach was introduced to correct the river network formation in SWAT model.

Precipitation is an important input of water in the hydrological cycle; hence, accurate and reliable precipitation information is therefore necessary to ensure better water resources management and decision-making. SPPs are widely accepted as an alternative source to overcome the limitation of ground techniques. This study presents a more comprehensive evaluation across Malaysia than was previously available in term of the number of gauge stations, evaluated satellite products, and the evaluated aspects (rainfall intensity analysis and flood event assessment). Moreover, this study presents the first attempt to evaluate the uncertainty and rain-detection ability of each of the SPPs over Malaysia. This study can be a guide on the selection of better precipitation products and bias correction of the selected product over Malaysia for hydrological modelling.

Land use maps were derived from multi-temporal satellite sensors images, and then applied into the SWAT model to evaluate the impacts of past land-use and climate change on streamflow of the studied basins. The knowledge on how land-use change on basin hydrology is important for local authority and policy makers to formulate and implement effective strategies to minimize the undesirable effects of future land-use change.

Application of the SWAT model in hydrological cycle simulation is still limited in Malaysia. This study presents the first attempt to evaluate the applicability of SWAT in the Johor River Basin (JRB) and Kelantan River Basin (KRB). The modified SWAT model can reasonably represent better streamflow simulation of the studied basins in Malaysia. Besides that, the SWAT's calibrated parameters of both basins can act as a reference for researchers or water resources managers to calibrate the SWAT model in tropical regions.

Building on current scientific knowledge, this study investigates the potential of climate changes on streamflow characteristics, and the associated uncertainties in the climate projection. The modified QUEST-GSI methodology is the most comprehensive and up-to-date climate scenario that is designed particularly for the quantification of climate projection uncertainty on streamflow simulation. This methodology has contributed to new theoretical and knowledge on how to better quantify the future climate projection uncertainties. This methodology is not only applicable for the evaluation on hydrological modelling, but also other applications such as environmental and ecological modelling.

The hydrological cycle varies regionally and this study contributes to factual information about the local hydrological cycle. Fresh water is one of the most important elements for human survival. Large quantities of water are essential for agriculture, industrial and hydropower purposes. As streamflow is a measure of water availability (Milly *et al.*, 2005), so the impact of climate change on future streamflow is vital for policy makers and water managers to develop better adaptation planning in terms of formulation of policies for investments in irrigation systems, agriculture, hydropower production and flood protection.

1.7 Structure of Thesis

This thesis consists of six chapters. The first chapter presents the background of the study, statement of the problem, study objectives, scope of the study and the structure of thesis. Chaper two presents a review of the hydrological cycle, hydrological modelling, remote sensing in hydrological modelling, DEM uncertainty assessment, satellite precipitation uncertainty assessment, land-use change and hydrological modelling, climate change and hydrological modelling, GCMs, downscaling of GCMs, uncertainties of climate change, studies of climate change impacts on streamflow in Asia and Malaysia.

Chapter three presents the research methodology for this study, the selected study area, essential data sets, satellite data processing and validation, SWAT model modification and set up, historical land-use and climate change analaysis, modification of the QUEST-GSI methodology and application of the modified QUEST-GSI methodology in the calibrated SWAT.

Chapter four presents the main results of DEMs and SPPs validation, river network correction and bias correction of the selected satellite precipitation product. In chapter five, the main findings such as SWAT calibration and validation, GCMs performance evaluation, impacts and uncertainties of climate change on streamflow of the JRB and KRB are presented. Finally, the summary, conclusion and future work recommendations of the study are described in chapter six.

to simulate more the tropical hydrological cycle reliably, in order to gain better simulation results.

(d) More climate scenarios should be established to understand better the range of climate impacts on streamflow. In addition, the modified QUEST-GSI methodology should be applied to other regions to check its capability.

(e) A better ensemble of GCMs approach should be developed in order to evaluate potential climate impact on streamflow more effectively. For example, applying the weight factors to GCMs based on their performance in simulating historical climate variables.

REFERENCES

Abbaspour, K. C. (2012). *SWAT-CUP 2012: SWAT Calibration and Uncertainty Programs - A User Manual*. Switzerland: Swiss Federal Institute Aquatic Science and Technology.

Abbaspour, K. C., Van Genuchten, M. T., Schulin, R., and Schlappi, E. (1997). A Sequential Uncertainty Domain Inverse Procedure for Estimating Subsurface Flow and Transport Parameters. *Water Resour. Res.* 33(8), 1879-1892.

Abbaspour, K. C., Yang, J., Maximov, I., Siber, R., Bogner, K., Mieleitner, J., Zobrist, J., and Srinivasan, R. (2007). Modelling Hydrology and Water Quality in the Pre-Alpine/Alpine Thur Watershed using SWAT. *J. Hydrol.* 333(2-4), 413-430.

Acker, J. G., and Leptoukh, G. (2007). Online Analysis Enhances Use of NASA Earth Science Data. *EOS, Trans. Am. Geophys. Union.* 88(2), 14-17.

Adnan, N. A., and Atkinson, P. M. (2011). Exploring the Impact of Climate and Land Use Changes on Streamflow Trends in a Monsoon Catchment. *Int. J. Climat.* 31(6), 815-831.

Aich, V., Liersch, S., Vetter, T., Huang, S., Tecklenburg, J., Hoffmann, P., Koch, H., Fournet, S., Krysanova, V., M Ller, E. N., and Hattermann, F. F. (2014). Comparing Impacts of Climate Change on Streamflow in Four Large African River Basins. *Hydrol. Earth Syst. Sci.* 18(4), 1305-1321

Alansi, A. W., Amin, M. S. M., Halim, G. A., Shafri, H. Z. M., Thamer, A. M., Waleed, A. R. M., Aimrun, W., and Ezrin, M. H. (2009). The Effect of Development and Land Use Change on Rainfall-Runoff and Runoff-Sediment Relationships Under Humid Tropical Condition: Case Study of Bernam Watershed Malaysia. *Eur. J. of Sci. Res.* 31(1), 88-105.

Amin, M., Shaaban, A., Ohara, N., Kavvas, M., Chen, Z., Kure, S., and Jang, S. (2015). Climate Change Assessment of Water Resources in Sabah and Sarawak, Malaysia, Based on Dynamically-Downscaled GCM Projections Using a Regional Hydroclimate Model. *J. Hydrol. Eng.* DOI: 10.1061/(ASCE)HE.1943-5584.0001242.

Amini, A., Ali, T. M., Ghazali, A. H. B., Aziz, A. A. and Akib, S. M. (2011). Impacts of Land-Use Change on Streamflows in the Damansara Watershed, Malaysia. *Arab. J. Sci. Eng.* 36(5), 713-720.

Anderson, J. R., Hardy, E. E., Roach, J. T., and Re, W. (1976). *A Land Use and Land Cover Classification System for Use with Remote Sensor Data*. United States Geological Survey, Washingston, United States.

Apip, Takara, K., Yamashiki, Y., Sassa, K., Ibrahim, A. B., and Fukuoka, H. (2010). A Distributed Hydrological-Geotechnical Model using Satellite-Derived Rainfall Estimates for Shallow Landslide Prediction System at A Catchment Scale. *Landslides*. 7(3), 237-258.

Apsite, E., Bakute, A., Elferts, D., Kurpniece, L., and Pallo, I. (2011). Climate Change Impacts on River Runoff in Latvia. *Clim. Res.* 48(1), 57-71.

Arnell, N. W. (2011). Uncertainty in the Relationship between Climate Forcing and Hydrological Response in UK Catchments. *Hydrol. Earth Syst. Sci.* 15(5), 897-912.

Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R., Santhi, C., Harmel, R. D., Van Griensven, A., Van Liew, M. W., Kannan, N., and Jha, M. K. (2012). SWAT: Model Use, Calibration, and Validation. *Trans. ASABE.* 55(4), 1491-1508.

Arnold, J. G., Srinivasan, R., Muttiah, R. S., and Williams, J. R. (1998). Large Area Hydrologic Modeling and Assessment - Part 1: Model Development. *J. Am. Water Resour. As.* 34(1), 73-89.

Asadullah, A. M., Butts, M., Glennie, P., Lindgaard-J Rgens, P., Madsen, H., and Riegels, N. (2012). *Water Resources Climate Change: Guidelines.* Denmark: DHI Water and Environment.

Ashouri, H., Hsu, K. L., Sorooshian, S., Braithwaite, D. K., Knapp, K. R., Cecil, L. D., Nelson, B. R., and Prat, O. P. (2014). PERSIANN-CDR: Daily Precipitation Climate Data Record from Multi-Satellite Observations for Hydrological and Climate Studies. *B. Am. Meteorol. Soc.* 96(1), 69-83.

Athmania, D., and Achour, H. (2014). External Validation of the ASTER GDEM2, GMTED2010 and CGIAR-CSI-SRTM v4.1 Free Access Digital Elevation Models (DEMs) in Tunisia and Algeria. *Remote Sens.* 6(5), 4600-4620.

Awadalla, S., and Noor, I. M. (1991). Induced Climate Change on Surface Runoff in Kelantan Malaysia: A Preliminary Assessment. *Int. J. Water Resour. D.* 7(1), 53-59.

Babar, S., and Ramesh, H. (2015). Streamflow Response to Land Use-Land Cover Change over the Nethravathi River Basin, India. *J. Hydrol. Eng.* 20(10), 05015002.

Bajracharya, S. R., Palash, W., Shrestha, M. S., Khadgi, V. R., Duo, C., Das, P. J., and Dorji, C. (2015). Systematic Evaluation of Satellite-Based Rainfall Products over the Brahmaputra Basin for Hydrological Applications. *Adv. Meteorol.* 2015, 398587.

Barnett, T., Malone, R., Pennell, W., Stammer, D., Semtner, B., and Washington, W. (2004). The Effects of Climate Change on Water Resources in the West: Introduction and Overview. *Climatic Change.* 62(1-3), 1-11.

Barrett, D. J., Kuzmin, V. A., Walker, J. P., McVicar, T. R., and Draper, C. (2008). *Improving Stream Flow Forecasting by Integrating Satellite Observations, In Situ Data and Catchment Models using Model-Data Assimilation Methods*. eWater Cooperative Research Centre, Australia.

Barrett, E. C. (1993). Precipitation Measurement by Satellites: Towards Community Algorithms. *Adv. Space Res.* 13(5), 119-136.

Bates, B. C., Kundzewicz, Z. W., Wu, S., and Palutikof, J. P. (2008). *Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change*. Geneva: IPCC Secretariat.

Becker, A., Schneider, U., Meyer-Christoffer, A., Ziese, M., Finger, P., Stender, P., Heller, A., and Breidenbach, J. N. (2011). *GPCC Report for Years 2009 and 2010.* Global Precipitation Climatology Centre, Deutscher Wetterdienst, Offenbach, Germany.

Behrangi, A., Andreadis, K., Fisher, J. B., Turk, F. J., Granger, S., Painter, T., and Das, N. (2014). Satellite-Based Precipitation Estimation and Its Application for Streamflow Prediction over Mountainous Western U.S. Basins. *J. Appl. Meteor. Climatol.* 53(12), 2823-2842.

Beighley, R. E., Ray, R. L., He, Y., Lee, H., Schaller, L., Andreadis, K. M., Durand, M., Alsdorf, D. E., and Shum, C. K. (2011). Comparing Satellite Derived Precipitation Datasets using the Hillslope River Routing (HRR) Model in the Congo River Basin. *Hydrol. Process.* 25(20), 3216-3229.

Berezowski, T., Chormański, J., Batelaan, O., Canters, F., and Van de Voorde, T. (2012). Impact of Remotely Sensed Land-Cover Proportions on Urban Runoff Prediction. *Int. J. of Appl. Earth Obs. and Geoinf.* 16, 54-65.

Bieger, K., Hormann, G., and Fohrer, N. (2015). The Impact of Land Use Change in The Xiangxi Catchment (China) on Water Balance and Sediment Transport. *Reg. Environ. Change.* 15(3), 485-498.

Bjerklie, D. M., Lawrence Dingman, S., Vorosmarty, C. J., Bolster, C. H., and Congalton, R. G. (2003) Evaluating the Potential for Measuring River Discharge from Space. *J. Hydrol.* 278(1–4), 17-38.

Bonan, G. (1997). Effects of Land Use on the Climate of the United States. *Climatic Change.* 37(3), 449-486.

Bourdin, D. R., Fleming, S. W., and Stull, R. B. (2012). Streamflow Modelling: A Primer on Applications, Approaches and Challenges. *Atmos. Ocean.* 50(4), 507-536.

Brakenridge, G. R., Nghiem, S. V., Anderson, E., and Chien, S. (2005). Space-Based Measurement of River Runoff. *EOS, Trans. Am. Geophys. Union.* 86(19), 185-188.

Brown, A. E., Western, A. W., Mcmahon, T. A., and Zhang, L. (2013). Impact of Forest Cover Changes on Annual Streamflow and Flow Duration Curves. *J. Hydrol.* 483(0), 39-50.

Casse, C., Gosset, M., Peugeot, C., Pedinotti, V., Boone, A., Tanimoun, B. A., and Decharme, B. (2015). Potential of Satellite Rainfall Products to Predict Niger River Flood Eventsi Niamey. *Atmos. Res.* 163, 162-176.

Chang, C., Wang, Z., Macbride, J., and Liu, C.H. (2005). Annual Cycle of Southeast Asia Maritime Continent Rainfall and the Asymmetric Monsoon Transition. *J. Climate.* 18(2), 287-301.

Chaplot, V., Darboux, F., Bourennane, H., Leguédois, S., Silvera, N., and Phachomphon, K. (2006). Accuracy of Interpolation Techniques for the

Derivation of Digital Elevation Models in Relation To Landform Types and Data Density. *Geomorphology*. 77(1–2), 126-141.

Chawla, I., and Mujumdar, P. P. (2015). Isolating the Impacts of Land Use and Climate Change on Streamflow. *Hydrol. Earth Syst. Sci. Discuss.* 12(2), 2201-2242.

Cheema, M. J. M. and Bastiaanssen, W. G. M. (2012) Local Calibration of Remotely Sensed Rainfall from the TRMM Satellite for Different Periods and Spatial Scales in the Indus Basin. *Int. J. Remote Sens.* 33(8), 2603-2627.

Chen, J. X., Xia, J., Zhao, C. S., Zhang, S. F., Fu, G. B., and Ning, L. K. (2014). The Mechanism and Scenarios of How Mean Annual Runoff Varies with Climate Change In Asian Monsoon Areas. *J. Hydrol.* 517, 595-606.

Chien, H., Yeh, P. J. F., and Knouft, J. H. (2013). Modeling the Potential Impacts of Climate Change on Streamflow in Agricultural Watersheds of the Midwestern United States. *J. Hydrol.* 491, 73-88.

Chiu, L. S., Liu, Z., Vongsaard, J., Morain, S., Budge, A., Neville, P., and Bales, C. (2006). Comparison of TRMM and Water District Rain Rates over New Mexico. *Adv. Atmos. Sci.* 23(1), 1-13.

Chow V.T. *Open Channel Hydraulics*, New York: Mcgraw-Hill. 1959.

Congalton, R. G. (2010) Remote Sensing: An Overview. *Gisci. Remote Sens.* 47(4), 443-459.

Department of Statistics, Malaysia. (2010). *Population Distribution and Basic Demographic Characteristics 2010.* Malaysia: Department of Statistics Malaysia

Derin, Y., and Yilmaz, K. K. (2014). Evaluation of Multiple Satellite-Based Precipitation Products over Complex Topography. *J. Hydrometeorol.* 15(4), 1498-1516.

Dinku, T., Chidzambwa, S., Ceccato, P., Connor, S. J., and Ropelewski, C. F. (2008). Validation of High-Resolution Satellite Rainfall Products over Complex Terrain. *Int. Remote Sens*. 29(14), 4097-4110.

Dong, Y. S., Chang, H. C., Chen, W. T., Zhang, K., and Feng, R. L. (2015). Accuracy assessment of GDEM, SRTM, and DLR-SRTM in Northeastern China. *Geocarto Int.* 30(7), 779-792.

Duan, Z., and Bastiaanssen, W. G. M. (2013). First Results from Version 7 TRMM 3B43 Precipitation Product in Combination with a New Downscaling–Calibration Procedure. *Remote Sens. Environ*. 131(0), 1-13.

Fan, J., Tian, F., Yang, Y. H., Han, S. M., and Qiu, G. Y. (2010). Quantifying the Magnitude of the Impact of Climate Change and Human Activity on Runoff Decline in Mian River Basin, China. *Water Sci. Technol.* 62(4), 783-791.

Feidas, H. (2010). Validation of Satellite Rainfall Products Over Greece. *Theor. Appl. Climatol*. 99(1-2), 193-216.

Ficklin, D. L., Stewart, I. T., and Maurer, E. P. (2013a). Climate Change Impacts On Streamflow And Subbasin-Scale Hydrology In The Upper Colorado River Basin. *Plos One,* 8(8), e71297.

Ficklin, D. L., Stewart, I. T., and Maurer, E. P. (2013b). Effects of Projected Climate Change on the Hydrology in the Mono Lake Basin, California. *Climatic Change,* 116(1), 111-131.

Ficklin, D. L., Luo, Y. Z., and Zhang, M. H. (2013c). Climate Change Sensitivity Assessment of Streamflow and Agricultural Pollutant Transport in California's Central Valley using Latin Hypercube Sampling. *Hydrol. Process.* 27(18), 2666-2675.

Fowler, H. J., Blenkinsop, S., and Tebaldi, C. (2007). Linking Climate Change Modelling to Impacts Studies: Recent Advances in Downscaling Techniques for Hydrological Modelling. *Int. J. Climatol.* 27(12), 1547-1578.

Fuchs, T., Schneider, U., Meyer-Christoffer, A., Finger, P., Breidenbach, J. N., Heller, A., Stender, P., and Rudolf, B. (2009). *GPCC Annual Report for Year 2008.* Global Precipitation Climatology Centre, Deutscher Wetterdienst, Offenbach, Germany.

Gain, A. K., Immerzeel, W. W., Weiland, F. C. S., and Bierkens, M. F. P. (2011). Impact of Climate Change on the Stream Flow of the Lower Brahmaputra: Trends in High and Low Flows Based on Discharge-Weighted Ensemble Modelling. *Hydrol. Earth Syst. Sci.* 15(5), 1537-1545.

Gao, P., Jiang, G. T., Wei, Y. P., Mu, X. M., Wang, F., Zhao, G.J., and Sun, W. Y. (2015). Streamflow Regimes of the Yanhe River under Climate and Land Use Change, Loess Plateau, China. *Hydrol. Process.* 29(10), 2402-2413.

Gassman, P. W., Reyes, M. R., Green, C. H., and Arnold, J. G. (2007). The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions. *Trans. ASABE,* 50(4), 1211-1250.

Genz, F., and Tanajura, C. A. S. (2013). Trends and Variability of Climate and River Flow in the Region of Costa Das Baleias, Brazil. *Water Sci. Technol.* 67(1), 47-54.

Getirana, A. C. V., Bonnet, M. P., Rotunno Filho, O. C., and Mansur, W. J. (2009). Improving Hydrological Information Acquisition from DEM Processing in Floodplains. *Hydrol. Process.* 23(3), 502-514.

Ghaffari, G., Keesstra, S., Ghodousi, J., and Ahmadi, H. (2010). SWAT-Simulated Hydrological Impact of Land-Use Change in the Zanjanrood Basin, Northwest Iran. *Hydrol. Process.* 24(7), 892-903.

Gleick, P. H. (1993). *Water in Crisis: A Guide to the World's Freshwater Resources.* United Kingdom: Oxford University Press.

Gonga-Saholiariliva, N., Gunnell, Y., Petit, C., and Mering, C. (2011). Techniques for Quantifying the Accuracy of Gridded Elevation Models and for Mapping Uncertainty in Digital Terrain Analysis. *Prog. Phys. Geog.* 35(6), 739-764

Green, W. H., and Ampt, G. A. (1911). Studies on Soil Physics: Part 1 The Flow of Air and Water Through Soils. *J. Agr. Sci.* 4(1), 1-24.

Gupta, H., Sorooshian, S., and Yapo, P. (1999). Status of Automatic Calibration for Hydrologic Models: Comparison with Multilevel Expert Calibration. *J. Hydrol. Eng.* 4(2), 135-143.

Gupta, P. K., Panigrahy, S., and Parihar, J. S. (2011). Impact of Climate Change on Runoff of The Major River Basins Of India Using Global Circulation Model (HadCM3) Projected Data. *J. Indian Soc. Remote,* 39(3), 337-344.

Hall, F. R. (1968). Base-Flow Recessions—A Review. *Water Resour. Res.,* 4(5), 973-983.

Hannaford, J. (2015). Climate-Driven Changes in UK River Flows: A Review of the Evidence. *Prog. Phys. Geog.* 39(1), 29-48.

Harding, B. L., Wood, A. W., and Prairie, J. R. (2012). The Implications of Climate Change Scenario Selection for Future Streamflow Projection in the Upper Colorado River Basin. *Hydrol. Earth Syst. Sci.* 16(11), 3989-4007.

Hargreaves, G. L., Hargreaves, G. H., and Riley, J. (1985). Agricultural Benefits for Senegal River Basin. *J. Irrig. Drain. Eng.* 111(2), 113-124.

Harmon, R. S., Lyons, W. B., Long, D. T., Ogden, F. L., Mitasova, H., Gardner, C. B., Welch, K. A., and Witherow, R. A. (2009). Geochemistry of Four Tropical Montane Watersheds, Central Panama. *Appl. Geochem.* 24(4), 624-640.

Harmsen, E. W., Mesa, S .E. G., Cabassa, E., Ram ŕez-Beltran, N. D., Pol, S. C., Kuligowski, R. J., And Vasquez, R. (2008). Satellite Sub-Pixel Rainfall Variability. *Int. J. Syst. Eng. Development.* 2(3), 91-100.

Hassan, Z., Shamsudin, S., Harun, S., Malek, M. A., and Hamidon, N. (2015). Suitability of ANN Applied as a Hydrological Model Coupled with Statistical Downscaling Model: a Case Study in the Northern Area of Peninsular Malaysia. *Environ. Earth Sci.* 74(1), 463-477.

Hay, L. E., Wilby, R. J. L., and Leavesley, G. H. (2000). A Comparison of Delta Change and Downscaled GCM Scenarios for Three Mountainous Basins in the United States. *J. Am. Water Resour. As.* 36(2), 387-397.

Herschy, R. W. (2009). *Streamflow Measurement.* (3rd ed.). 270 Madison Avenue, New York, Ny 10016, USA: Taylor And Francis.

Hijioka, Y., Lin, E., Pereira, J. J., Corlett, R. T., Cui, X., Insarov, G. E., Lasco, R. D., Lindgren, E., and Surjan, A. (2014). Asia. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: *Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. Maccracken, P.R. Mastrandrea, And L.L. White (Eds.)]*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1439-1498.

Hilton, R. G., Galy, A., Hovius, N., Chen, M. C., Horng, M. J., and Chen, H. (2008). Tropical-Cyclone-Driven Erosion of the Terrestrial Biosphere from Mountains. *Nature Geosci.* 1(11), 759-762.

Hirpa, F. A., Hopson, T. M., De Groeve, T., Brakenridge, G. R., Gebremichael, M., and Restrepo, P.J. (2013). Upstream satellite remote sensing for river discharge forecasting: Application to major rivers in South Asia. *Remote Sens. Environ*. 131(0), 140-151.

Hu, Q., Yang, D., Li, Z., Mishra, A. K., Wang, Y., and Yang, H. (2014). Multi-Scale Evaluation of Six High-Resolution Satellite Monthly Rainfall Estimates over a Humid Region in China with Dense Rain Gauges. *Int. J. Remote Sens*. 35(4), 1272-1294.

Huffman, G. J., and Bolvin, D. T. (2014). *TRMM and Other Data Precipitation Data Set Documentation.* Mesoscale Atmospheric Processes Laboratory, NASA Goddard Space Flight Center, Washington, United States.

Huffman, G. J., Adler, R. F., Bolvin, D. T., Gu, G. J., Nelkin, E. J., Bowman, K. P., Hong, Y., Stocker, E. F., and Wolff, D. B. (2007). The TRMM Multisatellite Precipitation Analysis (TMPA): Quasi-Global, Multiyear, Combined-Sensor Precipitation Estimates at Fine Scales. *J. Hydrometeor.* 8(1), 38-55.

Huffman, G. J., Adler, R. F., Morrissey, M. M., Bolvin, D. T., Curtis, S., Joyce, R., McGavock, B., and Susskind, J. (2001). Global Precipitation at One-Degree Daily Resolution from Multisatellite Observations. *J. Hydrometeor.* 2(1), 36-50.

Hughes, D. A., Kingston, D. G., and Todd, M. C. (2011). Uncertainty in Water Resources Availability in the Okavango River Basin as a Result of Climate Change. *Hydrol. Earth Syst. Sci.* 15(3), 931-941.

Huntington, T. G. (2006). Evidence for Intensification of the Global Water Cycle: Review And Synthesis. *J. Hydrol.* 319(1-4), 83-95.

IPCC. (2007). *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [Parry, M.L., Canziani, O.F., Palutikof, J.P., Van Der Linden, P.J., and Hanson, C.E. (Eds)]*. Cambridge, United Kingdom.

IPCC. (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. *A Special Report Of Working Groups I And II of The Intergovernmental Panel on Climate Change [Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.K., Allen, S.K., Tignor, M., and Midgley, P.M. (Eds.)]*. Cambridge, United Kingdom, and New York, NY, USA.

IPCC. (2013). *Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report* *of the Intergovernmental Panel On Climate Change. [Stocker, T. F., Qin, D., Plattner, G.K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., and Midgley, P.M. (Eds.)]*. Cambridge, United Kingdom, and New York, NY, USA.

Islam, A., Sikka, A. K., Saha, B., and Singh, A. (2012). Streamflow Response to Climate Change in the Brahmani River Basin, India. *Water Resour. Manag.* 26(6), 1409-1424.

Jackson, T. J., Schmugge, J. and Engman, E. T. (1996). Remote Sensing Applications to Hydrology: Soil Moisture. *Hydrol. Sci. J.* 41(4), 517-530.

Jakeman, A. J., and Hornberger, G. M. (1993). How Much Complexity is warranted in a Rainfall-Runoff Model. *Water Resour. Res.* 29(8), 2637-2649.

Jamandre, C. A., and Narisma, G. T. (2013). Spatio-Temporal Validation of Satellite-Based Rainfall Estimates in the Philippines. *Atmos. Res.* 122(0), 599-608.

Jayawardena, A.W., Takeuchi K., and Machbub, B., (1997). Catalogue of Rivers for Southeast Asia and the Pacific-Volume II. *The UNESCO-IHP Regional Sterring Committee for Southeast Asia and The Pacific, 2*(8), 214-223.

Jiang, T., Chen, Y. Q. D., Xu, C. Y. Y., Chen, X. H., Chen, X., and Singh, V. P. (2007). Comparison of Hydrological Impacts of Climate Change Simulated by Six Hydrological Models in the Dongjiang Basin, South China. *J. Hydrol.* 336(3-4), 316-333.

Jiménez Cisneros, B. E., Oki, T., Arnell, N. W., Benito, G., Cogley, J. G., D Ll, P., Jiang, T., and Mwakalila, S. S. (2014). *Freshwater Resources. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., Maccracken, S., Mastrandrea, P.R., and White, L.L. (Eds.)]*. Cambridge, United Kingdom and New York: Cambridge University Press.

Jin, X., and Sridhar, V. (2012). Impacts of Climate Change on Hydrology and Water Resources in the Boise and Spokane River Basins. *J. Am. Water Resour. As.* 48(2), 197-220.

Jing, C. W., Shortridge, A., Lin, S. P., and Wu, J. P. (2014). Comparison and Validation of SRTM and ASTER GDEM for a Subtropical Landscape in Southeastern China. *Int. J. Digit. Earth.* 7(12), 969-992.

Johnson, T., Butcher, J., Deb, D., Faizullabhoy, M., Hummel, P., Kittle, J., McGinnis, S., Mearns, L. O., Nover, D., Parker, A., Sarkar, S., Srinivasan, R., Tuppad, P., Warren, M., Weaver, C., and Witt, J. (2015). Modeling Streamflow and Water Quality Sensitivity to Climate Change and Urban Development in 20 US Watersheds. *J. Am. Water Resour. As.* 51(5), 1321-1341.

Joyce, R. J., Janowiak, J. E., Arkin, P. A., and Xie, P. P. (2004). CMORPH: A Method that Produces Global Precipitation Estimates from Passive Microwave And Infrared Data at High Spatial and Temporal Resolution. *J. Hydrometeor.* 5(3), 487-503.

Juneng, L., Tangang, F. T., Kang, H. W., Lee, W. J., and Seng, Y. K. (2010). Statistical Downscaling Forecasts for Winter Monsoon Precipitation in Malaysia using Multimodel Output Variables. *J. Climate*, 23(1), 17-27.

Kabiri, R., Bai, V. R. and Chan, A. (2015). Assessment of Hydrologic Impacts of Climate Change on the Runoff Trend in Klang Watershed, Malaysia. *Environ. Earth Sci.* 73(1), 27-37.

Kankam-Yeboah, K., Obuobie, E., Amisigo, B., and Opoku-Ankomah, Y. (2013). Impact of Climate Change on Streamflow in Selected River Basins in Ghana. *Hydrolog. Sci. J.* 58(4), 773-788.

Katiraie-Boroujerdy, P. S., Nasrollahi, N., Hsu, K. l., and Sorooshian, S. (2013). Evaluation of Satellite-Based Precipitation Estimation over Iran. *J. Arid Environ*. 97(0), 205-219.

Kay, A. L., Davies, H. N., Bell, V. A., and Jones, R. G. (2009). Comparison of Uncertainty Sources for Climate Change Impacts: Flood Frequency in England. *Climatic Change*, 92(1-2), 41-63.

Khan, S. I., Hong, Y., Gourley, J. J., Khattak, M. U. K., Yong, B., and Vergara, H. J. (2014). Evaluation of Three High-Resolution Satellite Precipitation Estimates: Potential for Monsoon Monitoring over Pakistan. *Adv. Space Res.* 54(4), 670-684.

Khoi, D. N., and Suetsugi, T. (2012). Uncertainty in Climate Change Impacts on Streamflow in Be River Catchment, Vietnam. *Water Environ. J.* 26(4), 530-539.

Khoi, D. N., and Suetsugi, T. (2014a). Impact of Climate and Land-Use Changes on Hydrological Processes and Sediment Yield-A Case Study of the Be River Catchment, Vietnam. *Hydrolog. Sci. J.* 59(5), 1095-1108.

Khoi, D. N., and Suetsugi, T. (2014b). The Responses of Hydrological Processes and Sediment Yield to Land-Use and Climate Change in the Be River Catchment, Vietnam. *Hydrol. Process.* 28(3), 640-652.

Kia, M. B., Pirasteh, S., Pradhan, B., Mahmud, A. R., Sulaiman, W. N. A., and Moradi, A. (2012). An Artificial Neural Network Model for Flood Simulation using GIS: Johor River Basin, Malaysia. *Environ. Earth Sci.* 67(1), 251-264.

Kidd, C. and Levizzani, V. (2011). Status of Satellite Precipitation Retrievals. *Hydrol. Earth Syst. Sc.* 15(4), 1109-1116.

Kim, H. K., Parajuli, P. B., and To, S. D. F. (2013). Assessing Impacts of Bioenergy Crops and Climate Change on Hydrometeorology in the Yazoo River Basin, Mississippi. *Agr. Forest Meteorol.* 169, 61-73.

Kingston, D. G., and Taylor, R. G. (2010). Sources of Uncertainty in Climate Change Impacts on River Discharge and Groundwater in a Headwater Catchment of the Upper Nile Basin, Uganda. *Hydrol. Earth Syst. Sci.* 14(7), 1297-1308.

Kingston, D. G., Thompson, J. R., and Kite, G. (2011). Uncertainty in Climate Change Projections of Discharge for the Mekong River Basin. *Hydrol. Earth Syst. Sci.* 15(5), 1459-1471.

Kirkby, M., Bracken, L., and Reaney, S. (2002). The Influence of Land Use, Soils and Topography on the Delivery of Hillslope Runoff to Channels in Se Spain. *Earth Surf. Proc. Land.* 27(13), 1459-1473.

Kite, G. W., and Pietroniro, A. (1996). Remote Sensing Applications in Hydrological Modelling. *Hydrol. Sci. J.* 41(4), 563-591.

Knutti, R., Abramowitz, G., Collins, M., Eyring, V., Gleckler, P. J., Hewitson, B., and Mearns, L. (2010). *Good Practice Guidance Paper on Assessing and Combining Multi Model Climate Projections. In: Meeting Report of the Intergovernmental Panel on Climate Change Expert Meeting on Assessing and*

Combining Multi Model Climate Projections. IPCC Working Group I Technical Support Unit, University of Bern, Bern, Switzerland.

Kovacs, A., and Clement, A. (2009). Impacts of the Climate Change on Runoff and Diffuse Phosphorus Load to Lake Balaton (Hungary). *Water Sci. Technol.* 59(3), 417-423.

Kummerow, C., Hong, Y., Olson, W. S., Yang, S., Adler, R. F., McCollum, J., Ferraro, R., Petty, G., Shin, D. B., and Wilheit, T. T. (2001). The Evolution of the Goddard Profiling Algorithm (GPROF) for Rainfall Estimation from Passive Microwave Sensors. *J. Appl. Meteorol.* 40(11), 1801-1820.

Kurtzman, D., Navon, S., and Morin, E. (2009). Improving Interpolation of Daily Precipitation for Hydrologic Modelling: Spatial Patterns of Preferred Interpolators. *Hydrol. Proces*. 23(23), 3281-3291.

Larson, L. W., and Peck, E. L. (1974). Accuracy of Precipitation Measurements for Hydrologic Modeling. *Water Resour. Res.* 10(4), 857-863.

Le, T. B., and Sharif, H. O. (2015). Modeling the Projected Changes of River Flow in Central Vietnam under Different Climate Change Scenarios. *Water.* 7(7), 3579-3598.

Lenderink, G., Buishand, A., and Van Deursen, W. (2007). Estimates of Future Discharges of the River Rhine using Two Scenario Methodologies: Direct versus Delta Approach. *Hydrol. Earth Syst. Sci.* 11(3), 1145-1159.

Levesque, E., Anctil, F., van Griensven, A., and Beauchamp, N. (2008). Evaluation of Streamflow Simulation by SWAT Model for Two Small Watersheds under Snowmelt and Rainfall. *Hydrol. Sci. J.* 53(5), 961-976.

Li, H., Zhang, Y., Chiew, F. H. S., and Xu, S. (2009). Predicting Runoff in Ungauged Catchments by using Xinanjiang Model with MODIS Leaf Area iIndex. *J. Hydrol.* 370(1–4), 155-162.

Li, P., Shi, C., Li, Z. H., Muller, J. P., Drummond, J., Li, X. Y., Li, T., Li, Y. B., and Liu, J. N. (2013). Evaluation of ASTER GDEM using GPS Benchmarks and SRTM in China. *Int. J. Remote Sen.* 34(5), 1744-1771.

Li, Z., Liu, W. Z., Zhang, X. C., and Zheng, F. L. (2009). Impacts of Land Use Change and Climate Variability on Hydrology in an Agricultural Catchment on the Loess Plateau of China. *J. Hydrol.* 377(1-2), 35-42.

Li, Z., Yang, D. W., and Hong, Y. (2013). Multi-Scale Evaluation of High-Resolution Multi-Sensor Blended Global Precipitation Products over The Yangtze River. *J. Hydrol.* 500, 157-169.

Li, Z. H., Deng, X. Z., Wu, F., and Hasan, S. S. (2015). Scenario Analysis for Water Resources in Response to Land Use Change in the Middle and Upper Reaches of the Heihe River Basin. *Sustainability.* 7(3), 3086-3108.

Lin, S., Jing, C., Coles, N., Chaplot, V., Moore, N., and Wu, J. (2013). Evaluating DEM Source and Resolution Uncertainties in the Soil and Water Assessment Tool. *Stoch. Env. Res. Risk A.* 27(1), 209-221.

Lin, Y. P., Hong, N. M., Wu, P. J., and Lin, C. J. (2007). Modeling and Assessing Land-Use and Hydrological Processes to Future Land-Use and Climate Change Scenarios in Watershed Land-Use Planning. *Environ. Geol.* 53(3), 623-634.

Liu, C. T., and Zipser, E. J. (2009). "Warm Rain" in the Tropics: Seasonal and Regional Distributions based on 9 Yr of TRMM Data. *J. Climate.* 22(3), 767-779.

Liu, W. B., Cai, T. J., Fu, G. B., Zhang, A. J., Liu, C. M., and Yu, H.Z. (2013) The Streamflow Trend in Tangwang River Basin in Northeast China and Its Difference Response to Climate and Land Use Change In Sub-Basins. *Environ. Earth Sci.* 69(1), 51-62.

Lloret, E., Dessert, C., Gaillardet, J., Alberic, P., Crispi, O., Chaduteau, C., and Benedetti, M. F. (2011). Comparison of Dissolved Inorganic and Organic Carbon Yields and Fluxes in the Watersheds of Tropical Volcanic Islands, Examples from Guadeloupe (French West Indies). *Chem. Geol.* 280(1-2), 65-78.

Lo Conti, F., Hsu, K. L., Noto, L. V., and Sorooshian, S. (2014). Evaluation and Comparison of Satellite Precipitation Estimates with Reference to a Local Area in the Mediterranean Sea. *Atmos. Res*. 138(0), 189-204.

Luo, Y., Su, B., Yuan, J., Li, H., and Zhang, Q. (2011). GIS Techniques for Watershed Delineation of SWAT Model in Plain Polders. *Procedia Environ. Sci.* 10(C), 2050-2057.

Mashingia, F., Mtalo, F., and Bruen, M. (2014). Validation of Remotely Sensed Rainfall over Major Climatic Regions in Northeast Tanzania. *Phys. Chem. Earth*. 67-69, 55-63.

Mateus, C., Tullos, D. D., and Surfleet, C. G. (2015). Hydrologic Sensitivity to Climate and Land Use Changes in the Santiam River Basin, Oregon. *J. Am. Water Resour. As.* 51(2), 400-420.

Maurer, E. P., Adam, J. C., and Wood, A. W. (2009). Climate Model Based Consensus on the Hydrologic Impacts of Climate Change to the Rio Lempa Basin of Central America. *Hydrol. Earth Syst. Sci.* 13(2), 183-194.

McPhee, J., and Margulis, S. A. (2005). Validation and Error Characterization of the GPCP-1DD Precipitation Product over the Contiguous United States. *J. Hydrometeor.* 6(4), 441-459.

Meenu, R., Rehana, S., and Mujumdar, P. P. (2013). Assessment of Hydrologic Impacts of Climate Change in Tunga-Bhadra River Basin, India with HEC-HMS and SDSM. *Hydrol. Process.* 27(11), 1572-1589.

Mehdi, B., Lehner, B., Gombault, C., Michaud, A., Beaudin, I., Sottile, M. F., and Blondlot, A. (2015). Simulated Impacts of Climate Change and Agricultural Land Use Change on Surface Water Quality With and Without Adaptation Management Strategies. *Agr. Ecosyst. Environ*. 213, 47-60.

Meinshausen, M., Smith, S. J., Calvin, K., Daniel, J. S., Kainuma, M. L. T., Lamarque, J. F., Matsumoto, K., Montzka, S. A., Raper, S. C. B., Riahi, K., Thomson, A., Velders, G. J. M., and Vuuren, D. P. P. (2011). The RCP Greenhouse Gas Concentrations and Their Extensions from 1765 to 2300. *Climatic Change.* 109(1-2), 213-241

Memarian, H., Balasundram, S. K., Abbaspour, K. C., Talib, J. B., Sung, C. T. B., and Sood, A. M. (2014). SWAT-based Hydrological Modelling of Tropical Land Use Scenarios. *Hydrol. Sci. J.* 59(10), 1808-1829.

Memarian, H., Balasundram, S. K., Talib, J. B., Sung, C. T. B., Sood, A. M., and Abbaspour, K. C. (2013). KINEROS2 Application for Land Use/Cover Change Impact Analysis at the Hulu Langat Basin, Malaysia. *Water Environ. J.* 27(4), 549-560.

Michaelides, S., Levizzani, V., Anagnostou, E., Bauer, P., Kasparis, T. and Lane, J. E. (2009). Precipitation: Measurement, Remote Sensing, Climatology and Modeling. *Atmos. Res.* 94(4), 512-533.

Milly, P. C. D., Dunne, K. A., and Vecchia, A. V. (2005). Global Pattern of Trends in Streamflow and Water Availability in a Changing Climate. *Nature*. 438(7066), 347-350.

Milly, P. C. D., Wetherald, R. T., Dunne, K. A., and Delworth, T. L. (2002). Increasing Risk of Great Floods in a Changing Climate. *Nature*. 415(6871), 514-517.

Mishra, A., Gairola, R. M., Varma, A. K., and Agarwal, V. K. (2010). Remote Sensing of Precipitation over Indian Land and Oceanic Regions by Synergistic use of Multisatellite Sensors. *J. Geophys. Res. – Atmos.* 115(D8), D08106.

Mispan, M. R., Rasid, M. Z. A., Rahman, N. F. A., Khalid, K., Haron, S. H., and Ahmad, N. (2015). Assessment of ASTER and SRTM Derived Digital Elevation Model for Highland Areas of Peninsular Malaysia Region. *Int. Res. J. Eng. Technol.* 2(6), 316-320.

Moazami, S., Golian, S., Kavianpour, M. R., and Hong, Y. (2013) Comparison of PERSIANN and V7 TRMM Multi-satellite Precipitation Analysis (TMPA) Products with Rain Gauge Data over Iran. *Int. J. Remote Sens.* 34(22), 8156-8171.

Monteith, J.L. (1965) Evaporation and the Environment. In: The Sate and Movement of Water in Living Organism. *19th Symposium on the Society of Experimental Biology*, 1965. Cambridge University Press, Cambridge, 205-234.

Moore, I. D., Grayson, R. B., and Ladson, A.R. (1991). Digital Terrain Modeling - A Review of Hydrological, Geomorphological, and Biological Applications. *Hydrol. Process.* 5(1), 3-30.

Moriasi, D. N., Arnold, J.G., Van Liew, M.W., Binger, R.L., Harmel, R.D., and Veith, T. (2007). Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. *Trans. ASABE.* 50(3), 885-900.

Moss, R. H., Edmonds, J. A., Hibbard, K. A., Manning, M. R., Rose, S. K., Van Vuuren, D. P., Carter, T. R., Emori, S., Kainuma, M., Kram, T., Meehl, G. A., Mitchell, J. F. B., Nakicenovic, N., Riahi, K., Smith, S. J., Stouffer, R. J., Thomson, A. M., Weyant, J. P., and Wilbanks, T. J. (2010). The Next Generation of Scenarios for Climate Change Research and Assessment. *Nature.* 463, 747-756.

Mukherjee, S., Joshi, P. K., Mukherjee, S., Ghosh, A., Garg, R. D., and Mukhopadhyay, A. (2013). Evaluation of Vertical Accuracy of Open Source Digital Elevation Model (DEM). *Int. J. Appl. Earth Obs. Geoinf.* 21, 205-217.

Nash, J. E., and Sutcliffe, J. V. (1970). River Flow Forecasting through Conceptual Models Part I — A Discussion of Principles. *J. Hydrol.* 10(3), 282-290.

Nazir, M. H. M., Sulaiman, W. N. A., and Juahir, H. (2015). Hydrologic Response Characteristics of A Tropical Catchment to Land Use Changes: A Case Study of the Nerus Catchment. *Environ. Earth Sci.* 73(11), 7533-7545.

Neitsch, S. L., Arnold, J. G., Kiniry, J. R., and Grassland, J. R. W. (2011). *Soil And Water Assessment Tool Theoretical Documentation Version 2009.* United State: Texas A&M University.

Ng, T. F. (2007). Assessment of Shuttle Radar Topographic Mission (SRTM) elevation data of Lojing and Hulu Langat, Peninsular Malaysia. *Warta Geologi*. 33(6), 250-264.

Nikolopoulos, E. I., Anagnostou, E. N., Hossain, F., Gebremichael, M., and Borga, M. (2010). Understanding the Scale Relationships of Uncertainty Propagation of Satellite Rainfall through a Distributed Hydrologic Model. *J. Hydrometeor*. 11(2), 520-532.

Nobrega, M. T., Collischonn, W., Tucci, C. E. M. and Paz, A. R. (2011). Uncertainty in Climate Change Impacts on Water Resources in the Rio Grande Basin, Brazil. *Hydrol. Earth Syst. Sci.* 15(2), 585-595.

Nyeko-Ogiramoi, P., Ngirane-Katashaya, G., Willems, P., and Ntegeka, V. (2010). Evaluation and Inter-Comparison of Global Climate Models' Performance over Katonga and Ruizi Catchments in Lake Victoria Basin. *Phys. Chem. Earth. Pt A/B/C,* 35(13-14), 618-633.

Oki, T., and Kanae, S. (2006). Global Hydrological Cycles and World Water Resources. *Science.* 313(5790), 1068-1072.

Opitz-Stapleton, S., Gangopadhyay, S., and Rajagopalan, B. (2007). Generating Streamflow Forecasts for the Yakima River Basin Using Large-Scale Climate Predictors. *J. Hydrol.* 341(3-4), 131-143.

Ouyang, F., Zhu, Y. H., Fu, G. B., Lu, H. S., Zhang, A. J., Yu, Z. B., and Chen, X. (2015). Impacts of Climate Change under CMIP5 RCP Scenarios on

Streamflow in the Huangnizhuang Catchment. *Stoch. Env. Res. Risk A.* 29(7), 1781-1795.

Öztürk, M., Copty, N. K., and Saysel, A. K. (2013). Modeling the Impact of Land Use Change on the Hydrology of a Rural Watershed. *J. Hydrol.* 497, 97-109.

Palmer, T. N., Doblas-Reyes, F. J., Weisheimer, A., and Rodwell, M. J. (2008). Toward Seamless Prediction: Calibration of Climate Change Projections using Seasonal Forecasts. *B. Am. Meteorol. Soc.* 89(4), 459-470.

Pan, X., Li, X., Yang, K., He, J., Zhang, Y., and Han, X. (2014). Comparison of Downscaled Precipitation Data over a Mountainous Watershed: A Case Study in the Heihe River Basin. *J. Hydrometeor*. 15(4), 1560-1574.

Pham, H. X., Shamseldin, A. Y., and Melville, B. W. (2015). Assessment of Climate Change Impact on Water Balance of Forested and Farmed Catchments. *J. Hydrol. Eng.* 20(10), 04015009.

Pietroniro, A., and Leconte, R. (2000). A Review of Canadian Remote Sensing Applications in Hydrology, 1995-1999. *Hydrol. Process.* 14(9), 1641-1666.

Pietroniro, A., and Leconte, R. (2005). A Review of Canadian Remote Sensing and Hydrology, 1999-2003*. Hydrol. Process.* 19(1), 285-301.

Pietroniro, A., and Prowse, T.D. (2002). Applications of Remote Sensing in Hydrology. *Hydrol. Process*. 16(8), 1537-1541.

Praskievicz, S., and Chang, H. J. (2009). A Review of Hydrological Modelling of Basin-Scale Climate Change and Urban Development Impacts. *Prog. Phys. Geog.* 33(5), 650-671.

Price, K. (2011). Effects of Watershed Topography, Soils, Land Use, and Climate on Baseflow Hydrology in Humid Regions: A Review. *Prog. Phys. Geog.* 35(4), 465-492.

Priestley, C. H. B., and Taylor, R. J. (1972). On the Assessment of Surface Heat Flux and Evaporation using Large-Scale Parameters. *Mon. Weather Rev.* 100(2), 81-92.

Prigent, C. (2010). Precipitation Retrieval from Space: An Overview. *C. R. Geosci.* 342(4–5), 380-389.

Pushparajah, E., and Amin, L. L. (1977). *Soils Under Hevea and Their Management In Peninsular Malaysia.* Kuala Lumpur, Malaysia: Lai Than Fong Press.

Raneesh, K. Y., and Santosh, G. T. (2011). A Study on the Impact of Climate Change on Streamflow at the Watershed Scale in the Humid Tropics. *Hydrolog. Sci. J.* 56(6), 946-965.

Rango, A. (1994). Application of Remote Sensing Methods to Hydrology and Water Resources. *Hydrol. Sci. J.* 39(4), 309-320.

Rao, M. N., and Yang, Z. (2010). Groundwater Impacts Due to Conservation Reserve Program in Texas County, Oklahoma. *Appl. Geogr.* 30(3), 317-328.

Ravazzani, G., Bocchiola, D., Groppelli, B., Soncini, A., Rulli, M. C., Colombo, F., Mancini, M., and Rosso, R. (2015). Continuous Streamflow Simulation for Index Flood Estimation in an Alpine Basin of Northern Italy. *Hydrol. Sci. J.* 60(6), 1013-1025.

Reuter, H. I., Nelson, A., and Jarvis, A. (2007). An Evaluation of Void-Filling Interpolation Methods for SRTM Data. *Int. J. Geogr. Inf. Sci.* 21(9), 983-1008.

Rexer, M., and Hirt, C. (2014). Comparison of Free High Resolution Digital Elevation Data Sets (ASTER GDEM2, SRTM V2.1/V4.1) and Validation against Accurate Heights from the Australian National Gravity Database. *Aust. J. Earth Sci.* 61(2), 213-226.

Riggs, H. C. 1985. *Streamflow Characteristics (Developments in Water Science). In:* Riggs, H. C. (Ed.). Elsevier.

Ritchie, J. C., and Rango, A. (1996). Remote Sensing Applications to Hydrology: Introduction. *Hydrol. Sci. J.* 41(4), 429-431.

Robinson, N., Regetz, J., and Guralnick, R. P. (2014). EarthENV-Dem90: A Nearly-Global, Void-free, Multi-Scale Smoothed, 90m Digital Elevation Model from Fused ASTER and SRTM Data. *ISPRS J. Photogramm.* 87, 57-67.

Rodriguez, E., Morris, C. S., Belz, J. E., Chapin, E. C., Martin, J. M., Daffer, W., and Hensley, S. (2005). *An Assessment of the SRTM Topographic Products. Technical Report JPL D-31639.* Jet Propulsion Laboratory, Pasadena, California.

Salathe, E. P., Mote, P. W., and Wiley, M. W. (2007). Review of Scenario Selection and Downscaling Methods for the Assessment of Climate Change Impacts on Hydrology in the United States Pacific Northwest. *Int. J. Climatol.* 27(12), 1611-1621.

Schneider, U., Becker, A., Meyer-Christoffer, A., Ziese, M., and Rudolf, B. (2011) *Global Precipitation Analysis Products of the GPCC*; DWD: Offenbach, Germany,

Semire, F. A., Mohd-Mokhtar, R., Ismail, W., Mohamad, N., and Mandeep, J. S. (2012). Ground Validation of Space-Borne Satellite Rainfall Products in Malaysia. *Adv. Space Res.* 50(9), 1241-1249.

Serpa, D., Nunes, J. P., Santos, J., Sampaio, E., Jacinto, R., Veiga, S., Lima, J. C., Moreira, M., Corte-Real, J., Keizer, J. J. and Abrantes, N. (2015). Impacts of climate and land use changes on the hydrological and erosion processes of two contrasting Mediterranean catchments. *Sci. Total Environ*. 538, 64-77.

Settele, J., Scholes, R., Betts, R., Bunn, S., Leadley, P., Nepstad, D., Overpeck, J. T., and Taboada, M. A. (2014). *Terrestrial and Inland Water Systems. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., Maccracken, S., Mastrandrea, P.R., and White, L.L. (Eds.)]*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Seyam, M., and Othman, F. (2015). Long-term variation analysis of a tropical river's annual streamflow regime over a 50-year period. *Theor. Appl. Climatol*. 121(1-2), 71-85.

Shaaban, A. J., Amin, M. Z. M., Chen, Z. Q. and Ohara, N. 2011. Regional Modeling of Climate Change impact on Peninsular Malaysia Water Resources. *J. Hydrol. Eng.,* 16, 1040-1049.

Shaibu, S., Odai, S. N., Adjei, K. A., Jnr, E. M. O., and Annor, F. O. (2012). Simulation of Runoff for the Black Volta Basin using Satellite Observation Data. *Int. J. River Basin Manage*. 10(3), 245-254.

Shen, Y., Xiong, A. Y., Wang, Y., and Xie, P. P. (2010). Performance of High-Resolution Satellite Precipitation Products over China. *J. Geophys. Res. – Atmos.* 115 (D2),

Shepherd, A., Gill, K. M., and Rood, S. B. (2010). Climate Change and Future Flows of Rocky Mountain Rivers: Converging Forecasts from Empirical Trend

Projection and Down-Scaled Global Circulation Modelling. *Hydrol. Process.* 24(26), 3864-3877.

Shepherd, T. G. (2014). Atmospheric Circulation as a Source of Uncertainty in Climate Change Projections. *Nature Geosci.* 7(10), 703-708.

Siew, J. H., Tangang, F. T., and Juneng, L. (2014). Evaluation of CMIP5 Coupled Atmosphere–Ocean General Circulation Models and Projection of the Southeast Asian Winter Monsoon in the 21st Century. *Int. J. Climatol.,* 34(9), 2872-2884

Silvestro, F., Gabellani, S., Rudari, R., Delogu, F., Laiolo, P., and Boni, G. (2015). Uncertainty Reduction and Parameter Estimation of a Distributed Hydrological Model with Ground and Remote-Sensing Data. *Hydrol. Earth Syst. Sci.* 19(4), 1727-1751.

Singh, V., and Woolhiser, D. (2002). Mathematical Modeling of Watershed Hydrology. *J. Hydrol. Eng.* 7(4), 270-292.

Skinner, C. J., Bellerby, T. J., Greatrex, H., and Grimes, D. I. F. (2015). Hydrological Modelling using Ensemble Satellite Rainfall Estimates in A Sparsely Gauged River Basin: The Need for Whole-Ensemble Calibration. *J. Hydrol.* 522, 110-122.

Smith, L. C., and Pavelsky, T. M. (2008). Estimation of River Discharge, Propagation Speed, and Hydraulic Geometry from Space: Lena River, Siberia. *Water Resour. Res.* 44(3), W03427.

Soulis, K. X., Dercas, N. and Papadaki, C. H. (2015). Effects of Forest Roads on the Hydrological Response of a Small-Scale Mountain Watershed in Greece. *Hydrol. Process*. 29(7), 1772-1782.

Strauch, M., Bernhofer, C., Koide, S., Volk, M., Lorz, C., and Makeschin, F. (2012). Using Precipitation Data Ensemble for Uncertainty Analysis in SWAT Streamflow Simulation. *J. Hydrol.* 414–415(0), 413-424.

Strzepek, K. M., Campos, M., Kaczmarek, Z., Sanchez, A., Yates, D. N., Carmichael, J., Chavula, G. M. S., Chirwa, A. B., Mirza, M., Minarik, B., and Warrick, R. (1998). *Water Resources. Chapter 6 in Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies (Version 2.0)*. United States: United Nations Environment Programme.

Suhaila, J., and Jemain, A. A. (2009). Investigating the Impacts of Adjoining Wet Days on the Distribution of Daily Rainfall Amounts in Peninsular Malaysia. *J. Hydrol*. 368(1-4), 17-25.

Sujan, K., Yukiko, H., Roobavannan, M., and Shinjiro, K. (2014). Global Assessment of Agreement among Streamflow Projections using CMIP5 Model Outputs. *Environ. Res. Lett.* 9(6), 064017.

Sun, G., Ranson, K. J., Khairuk, V. I., and Kovacs, K. (2003). Validation of Surface Height from Shuttle Radar Topography Mission using Shuttle Laser Altimeter. *Remote Sens. Environ.* 88(4), 401-411.

Sun, W. C., Ishidaira, H., Bastola, S., and Yu, J. S. (2015). Estimating Daily Time Series of Streamflow using Hydrological Model Calibrated Based on Satellite Observations of River Water Surface Width: Toward Real World Applications. *Environ. Res*. 139, 36-45.

Suwandana, E., Kawamura, K., Sakuno, Y., Kustiyanto, E. and Raharjo, B. (2012). Evaluation of ASTER GDEM2 in Comparison with GDEM1, SRTM DEM and Topographic-Map-Derived DEM Using Inundation Area Analysis and RTK-dGPS Data. *Remote Sens.* 4(8), 2419-2431.

Tachikawa, T., Kaku, M., Iwasaki, A., Gesch, D., Oimoen, M., Zhang, Z., Danielson, J., Krieger, T., Curtis, B., Haase, J., Abrams, M., Crippen, R., and Carabajal, C. (2011). *ASTER Global Digital Elevation Model Version 2 – Summary of Validation Results.* USA and Japan: National Aeronautics and Space Administration (NASA) and Ministry Economy, Trade and Industry (METI) of Japan

Tang, F. F., Xu, H. S., and Xu, Z. X. (2012). Model Calibration and Uncertainty Analysis for Runoff in the Chao River Basin Using Sequential Uncertainty Fitting. *18th Biennial Isem Conference On Ecological Modelling For Global Change And Coupled Human And Natural System.* 20-23 September 2011. Amsterdam, 1760-1770.

Tangang, F. T., Juneng, L., Salimun, E., Sei, K. M., Le, L. J., and Muhamad, H. (2012). Climate Change and Variability over Malaysia: Gaps in Science and Research Information. *Sains Malaysiana.* 41(11), 1355-1366.

Tangang, F. T., Juneng, L., Salimun, E., Vinayachandran, P. N., Seng, Y. K., Reason, C. J. C., Behera, S. K., and Yasunari, T. (2008). On the Roles of the Northeast

Cold Surge, the Borneo Vortex, the Madden-Julian Oscillation, and the Indian Ocean Dipole During the Extreme 2006/2007 Flood in Southern Peninsular Malaysia. *Geophys. Res. Lett*. 35(14).

Taxak, A. K., Murumkar, A. R., and Arya, D.S. (2014). Long Term Spatial and Temporal Rainfall Trends and Homogeneity Analysis in Wainganga Basin, Central India. *Weather Clim. Extremes* 4, 50-61.

Taye, M. T., Ntegeka, V., Ogiramoi, N. P., and Willems, P. (2011). Assessment of Climate Change Impact on Hydrological Extremes in Two Source Regions of the Nile River Basin. *Hydrol. Earth Syst. Sci.* 15(1), 209-222.

Teutschbein, C., Wetterhall, F., and Seibert, J. (2011). Evaluation of Different Downscaling Techniques for Hydrological Climate-Change Impact Studies at the Catchment Scale. *Clim. Dynam.* 37(9-10), 2087-2105.

Thampi, S. G., Raneesh, K. Y., and Surya, T. V. (2010). Influence of Scale on SWAT Model Calibration for Streamflow in a River Basin in the Humid Tropics. *Water Resour. Manag.* 24(15), 4567-4578.

Thomas, J., Joseph, S., Thrivikramji, K. P., and Arunkumar, K. S. (2014). Sensitivity of Digital Elevation Models: The Scenario from Two Tropical Mountain River Basins of the Western Ghats, India. *Geosci. Front.* 5(6), 893-909.

Thorne, R. (2011). Uncertainty in the Impacts of Projected Climate Change on the Hydrology of a Subarctic Environment: Liard River Basin. *Hydrol. Earth Syst. Sci.* 15(5), 1483-1492.

Tian, Y. D., and Peters-Lidard, C. D. (2010). A Global Map of Uncertainties in Satellite-Based Precipitation Measurements. *Geophys. Res. Lett.* 37(24).

Todd, M. C., Taylor, R. G., Osborn, T. J., Kingston, D. G., Arnell, N. W., and Gosling, S. N. (2011). Uncertainty In Climate Change Impacts On Basin-Scale Freshwater Resources - Preface To The Special Issue: The Quest-Gsi Methodology And Synthesis Of Results. *Hydrol. Earth Syst. Sci.* 15(3), 1035-1046.

Todini, E. (1988). Rainfall-Runoff Modeling — Past, Present and Future. *J. Hydrol.* 100(1-3), 341-352.

Trenberth, K. E., and Shea, D. J. (2005). Relationships between Precipitation and Surface Temperature. *Geophys. Res. Lett.* 32(14), L14703.

Trenberth, K. E., Dai, A., Rasmussen, R. M., and Parsons, D. B. (2003). The Changing Character of Precipitation. *B. Am. Meteorol. Soc.* 84(9), 1205-1217.

Tsai, A. Y., and Huang, W. C. (2011). Impact of Climate Change on Water Resources in Taiwan. *Terr. Atmos. Ocean. Sci.* 22(5), 507-519.

Tu, J. (2009). Combined Impact of Climate and Land Use Changes on Streamflow and Water Quality in Eastern Massachusetts, USA. *J. Hydrol.* 379(3-4), 268-283.

Tu, X. J., Singh, V. P., Chen, X. H., Chen, L., Zhang, Q., and Zhao, Y. (2015). Intra-annual Distribution of Streamflow and Individual Impacts of Climate Change and Human Activities in the Dongijang River Basin, China. *Water Resour. Manag.* 29(8), 2677-2695.

UNISDR. (2011). *Global Assessment Report on Disaster Risk Reduction 2011*. Geneva, Switzerland: United Nations International Strategy for Disaster Reduction.

Uniyal, B., Jha, M., and Verma, A. (2015). Assessing Climate Change Impact on Water Balance Components of a River Basin Using SWAT Model. *Water Resour. Manag*. 29(13), 4767-4785.

USDA-SCS. (1972) *National Engineering Handbook: Section 4. Hydrology*. Washington, United States: United States Department of Agriculture.

USGS. (2009). *Federal Guidelines, Requirements, and Procedures for the National Watershed Boundary Dataset.* United States Geological Survey, Washington, United States.

Van Griensven, A., Meixner, T., Grunwald, S., Bishop, T., Diluzio, M., Srinivasan, R. (2006). A global sensitivity analysis tool for the parameters of multi-variable catchment models. *J. Hydrol.* 324(1-4), 10-23.

Van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G. C., Kram, T., Krey, V., Lamarque, J. F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S. J., and Rose, S. K. (2011). The Representative Concentration Pathways: An Overview. *Climatic Change.* 109(1-2), 5-31.

Varga, M., and Basic, T. (2015). Accuracy Validation and Comparison of Global Digital Elevation Models over Croatia. *Int. J. Remote Sens*. 36(1), 170-189.

Varikoden, H., Samah, A. A., and Babu, C. A. (2010). Spatial and Temporal Characteristics of Rain Intensity in the Peninsular Malaysia using TRMM Rain Rate. *J. Hydrol.* 387(3-4), 312-319.

Vernimmen, R. R. E., Hooijer, A., Mamenun, Aldrian, E., and van Dijk, A. (2012). Evaluation and Bias Correction of Satellite Rainfall Data for Drought Monitoring in Indonesia. *Hydrol. Earth Syst. Sc*. 16(1), 133-146.

Vu, M. T., Raghavan, S. V., and Liong, S. Y. (2012). SWAT Use of Gridded Observations for Simulating Runoff – A Vietnam River Basin Study. *Hydrol. Earth Syst. Sci.* 16, 2801-2811.

Wang, S. J., Wang, Y. J., Ran, L. S., and Su, T. (2015) Climatic and Anthropogenic Impacts on Runoff Changes in the Songhua River Basin over the Last 56 Years (1955-2010), Northeastern China. *Catena.* 127, 258-269.

Wang, Z. G., Ficklin, D. L., Zhang, Y. Y., and Zhang, M. H. (2012). Impact of Climate Change on Streamflow in the Arid Shiyang River Basin of Northwest China. *Hydrol. Process.* 26(18), 2733-2744.

Wechsler, S. P. (2007). Uncertainties Associated with Digital Elevation Models for Hydrologic Applications: A Review. *Hydrol. Earth Syst. Sci.* 11(4), 1481-1500.

Wechsler, S. P., and Kroll, C. N. (2006). Quantifying DEM Uncertainty and Its Effect on Topographic Parameters. *Photogramm. Eng. Remote Sens*. 72(9), 1081-1090.

Wegehenkel, M., Heinrich, U., Uhlemann, S., Dunger, V., and Matschullat, J. (2006). The Impact of Different Spatial Land Cover Data Sets on the Outputs of A Hydrological Model – A Modelling Exercise in The Ucker Catchment, North-East Germany. *Phys. Chem. Earth, Pt. A/B/C*. 31(17), 1075-1088.

Wei, X. H., Liu, W. F., and Zhou, P.C. (2013). Quantifying the Relative Contributions of Forest Change and Climatic Variability to Hydrology in Large Watersheds: A Critical Review of Research Methods. *Water.* 5(2), 728-746.

Wilby, R. L., and Dawson, C. W. (2013). The Statistical Downscaling Model: Insights from One Decade of Application. *Int. J. Climatol.* 33(7), 1707-1719.

Wilby, R. L., and Harris, I. (2006). A Framework for Assessing Uncertainties in Climate Change Impacts: Low-Flow Scenarios for the River Thames, UK. *Water Resour. Res.* 42(2), W02419.

Wilby, R. L., and Wigley, T. M. L. (1997). Downscaling General Circulation Model Output: A Review of Methods and Limitations. *Prog. Phys. Geog.* 21(4), 530-548.

Wilby, R. L., Beven, K. J., and Reynard, N. S. (2008). Climate Change and Fluvial Flood Risk in the UK: More of the Same? *Hydrol. Process.* 22(14), 2511-2523.

Wilby, R. L., Charles, S. P., Zorita, E., Timbal, B., Whetton, P., and Mearns, L. O. (2004). *Guidelines for use of Climate Scenarios Developed from Statistical Downscaling Methods*. IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA)

Wilby, R. L., Dawson, C. W., and Barrow, E. M. (2002). SDSM - A Decision Support Tool for the Assessment of Regional Climate Change Impacts. *Environ. Model. Softw.* 17(2), 147-159.

Wilby, R. L., Troni, J., Biot, Y., Tedd, L., Hewitson, B. C., Smith, D. M., and Sutton, R. T. (2009). A Review of Climate Risk Information for Adaptation and Development Planning. *Int. J. Climatol.* 29(9), 1193-1215.

Williams J. R. 1969. Flood Routing With Variable Travel Time or Variable Storage Coefficients. *Trans. ASABE*. 12(1), 100-103.

WMO. (2012). *No. 8 - Guide to Meteorological Instruments and Methods of Observation.* World Meteorological Organization, Geneva 2, Switzerland.

Wohl, E., Barros, A., Brunsell, N., Chappell, N. A., Coe, M., Giambelluca, T., Goldsmith, S., Harmon, R., Hendrickx, J. M. H., Juvik, J., Mcdonnell, J., and Ogden, F. (2012). The Hydrology of the Humid Tropics. *Nature Climate Change.* 2(9), 655-662.

Wu, S. L., Bras, R. L., and Barros, A. P. (2006). Sensitivity of Channel Profiles to Precipitation Properties in Mountain Ranges. *J. Geophys. Res-Earth.* 111(F1), F01024.

Wu, S., Li, J., and Huang, G. H. (2008). A Study On DEM-Derived Primary Topographic Attributes For Hydrologic Applications: Sensitivity To Elevation Data Resolution. *Appl. Geogr.* 28(3), 210-223.

Xu, C. Y. (1999). Climate Change and Hydrologic Models: A Review of Existing Gaps and Recent Research Developments. *Water Resour. Manag.* 13(5), 369-382.

Xu, H., Taylor, R. G., and Xu, Y. (2011). Quantifying Uncertainty in the Impacts of Climate Change on River Discharge in Sub-Catchments of the Yangtze and Yellow River Basins, China. *Hydrol. Earth Syst. Sci.* 15(1), 333-344.

Xue, X. W., Hong, Y., Limaye, A. S., Gourley, J. J., Huffman, G. J., Khan, S. I., Dorji, C., and Chen, S. (2013) Statistical and Hydrological Evaluation of TRMM-

Based Multi-Satellite Precipitation Analysis over the Wangchu Basin of Bhutan: Are the Latest Satellite Precipitation Products 3B42V7 Ready for use in Ungauged Basins? *J. Hydrol.* 499, 91-99.

Yang, J., Reichert, P., Abbaspour, K. C., Xia, J., and Yang, H. (2008). Comparing Uncertainty Analysis Techniques for a SWAT Application to the Chaohe Basin in China. *J. Hydrol.* 358(1-2), 1-23.

Yilmaz, K. K., Hogue, T. S., Hsu, K. L., Sorooshian, S., Gupta, H. V., and Wagener, T. (2005). Intercomparison of Rain Gauge, Radar, and Satellite-Based Precipitation Estimates with Emphasis on Hydrologic Forecasting. *J. Hydrometeor.* 6(4), 497-517.

Yong, B., Liu, D., Gourley, J. J., Tian, Y., Huffman, G. J., Ren, L., and Hong, Y. (2014). Global View of Real-Time TRMM Multi-Satellite Precipitation Analysis: Implication to Its Successor Global Precipitation Measurement Mission. *Bull. Amer. Meteor. Soc.*, 96, 283-296.

Zeng, S. D., Xia, J., She, D. X., Du, H., and Zhang, L. P. (2012). Impacts of Climate Change on Water Resources in the Luan River Basin in North China. *Water Int.* 37(5), 552-563.

Zhang, D., Chen, X., Yao, H., and Lin, B. (2015). Improved Calibration Scheme of SWAT by Separating Wet and Dry Seasons. *Ecol. Model.* 301, 54-61.

Zhang, H., and Huang, G. (2009). Building Channel Networks for Flat Regions in Digital Elevation Models. *Hydrol. Process*. 23(20), 2879-2887.

Zhang, P., Liu, R., Bao, Y., Wang, J., Yu, W. and Shen, Z. (2014). Uncertainty of SWAT Model at Different DEM Resolutions in a Large Mountainous Watershed. *Water Res.* 53(0), 132-144.

Zhang, Q., Singh, V. P., Sun, P., Chen, X., Zhang, Z. X., and Li, J. F. (2011). Precipitation and Streamflow Changes in China: Changing Patterns, Causes and Implications. *J. Hydrol.*, 410(3-4), 204-216.

Zhao, Y., Zhang, X. M., Cao, W. H., Yu, X. X., Liu, B., Zhu, B. S., Cheng, C., Yin, X. L., and Xie, G. (2015). Effect of Climatic Change and Afforestation on Water Yield in the Rocky Mountain Area of North China. *Forest Syst*. 24(1), e104.